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US Army Corps of Engineers
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U.S. Army Construction Engineering Research Laboratory

SEMIHARDENED CONTINGENCY COMMUNICATION SHELTERS

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Prepared for the

Defense Communications Agency
Defense Communications Engineering Center
1860 Wiehle Avenue
Reston, Virginia 22090

Under
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FOREWORD

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The purpose of this analysis was to (1) investigate concepts that can be used in constructing semihardened shelters for Defense Communications Systems (DCS) prepositioned equipment or operations functions, (2) provide planners with parametric relationships that will simplify selection of the least expensive facility for any given location, threat, and function, and (3) present one case study applying the concepts found to be least costly to an AUTODIN Switch Facility.

The development process and case study comprise five sections in this report. The first describes the basic requirements and initial conceptual designs for the Transportable Unit Storage Shelter, the Reconstitutional Package Storage Shelter, and the Operational Shelter. While developing this section, design alternatives were considered, evaluated, and selected for use in the conceptual design and cost estimate. Rectangular cross section structures of cast-in-place concrete were selected as baseline design.

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The second section describes baseline buildings using a preengineered metal structure as the unhardened example and a standard ammunition igloo for the semihardened example. The concepts were developed to provide a comparative basis for addressing a "low first cost" criteria. Neither building could meet the threat definition no could they be modified easily to provide the needed hardness. The igloo would provide a low level of protection, however, and could be considered for use in some areas.

The third section addresses several construction alternatives, each designed to reduce the onsite construction time or the skilled labor demands. Two alternatives specifically discussed for the operational shelter would have limited usefulness for storing truck-mounted equipment.

The fourth section presents general explanations of the design method and construction cost estimates together with the major underlying assumptions. The important findings of the design and cost estimating aspects of this investigation are summarized. Also summarized are alternative construction concepts that satisfy the specified performance criteria for the various shelter types. The planner is completely responsible for selecting the most suitable shelter concept and construction technique at a specific geographical location.

In the final section the least-cost alternatives developed in prior sections are applied to an AUTODIN Switch Facility with a limited threat definition and different operational requirements. Facility configurations and cost estimates are presented.

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A INTRODUCTION

Purpose

The purpose of this analysis is to (1) investigate concepts that can be used in constructing semihardened shelters for Defense Communications Systems (DCS) prepositioned equipment or operations functions, (2) provide planners with parametric relationships that will simplify selection of the least expensive facility for any given location, threat, and function, and (3) present one case study applying the concepts found to be least costly to an AUTODIN Switch Facility.

Background

When examining wartime DCS facilities' performance requirements and solution options, a discrepancy in construction cost and level of protection provided is apparent between the present peacetime structures and those fully hardened redoubts capable of surviving direct hits by the heaviest conventional weapons. There is a need to resolve this discrepancy with an inventory of facility concepts using several construction techniques that provide a range of protection levels at minimized construction cost. Recent attention given to identifying storage facilities for contingency or reconstitution assets therefore has emphasized the need for facility concepts that can relate construction cost directly with the level of protection achieved.

Two competing schools of thought on DCS survivability both paradoxically support the development of such a concept. The first presupposes destruction of most DCS fixed assets at the outset of hostilities, thus placing the burden of command and control (CAC) communications responsibility on transportable equipment prepositioned in trucks, trailers, or vans. The second school takes a more optimistic perspective, suggesting that cost-effective steps can be taken to enhance the survivability of fixed sites so that a large percentage could remain operational at some level. For the damage inevitably experienced, prepositioned reconstitution packages are proposed to permit restoration of critical links and service.

Without attempting to resolve this difference in viewpoint, it should nevertheless be clear that the case for transportable communications units logically requires a storage plan which would provide much greater survivability than the vulnerable stations which the transportables are designed to replace. Basing the transportable units in an open motor pool or conventional warehouse sharply lowers the probability that a significant number will remain unscathed and ready for use soon after attack. The only reasonable alternative would be greater dispersion, but the need for physical security, logistic support, and long-term environmental protection makes this option less attractive for the DCS.

Similarly, the proponents of upgrading existing stations need a low-cost hardened shelter to store reconstitution packages. Warehouses and other bulk storage facilities are as unsuitable for this purpose as they are for transportable units, and for the same reason. Therefore,

some tradeoffs need to be investigated between space for reconstitution package storage and that for actual operations, along with the possibility of reducing the quantity and cost of reconstitutional assets at certain locations. Given the need for a low-cost, reasonably hardened shelter capable of enduring moderate blast and overpressure threats, a combination of construction techniques and support equipment configurations appears to offer the best potential solution.

The desired performance attributes for the proposed facility are:

1. Low first cost--no greater than 1.5 times equivalent nonhardened communication facility construction cost.

2. Rapid construction--no greater than 80 percent equivalent nonhardened construction time.

3. Endurability--capable of sustaining direct hits by heavy armor/concrete piercing ground weapons and near misses by 1.1-ton aerial ordnance without loss of structural integrity or major damage to personnel and equipment located inside.

4. Low operating cost--energy and maintenance cost no greater than 80 percent equivalent nonhardened construction.

Threat Definition

The major concern in developing semihardened shelters for Defense Communications Agency (DCA) equipment and personnel is to protect the stored contents against external attacks from the enemy. During these attacks, the shelters would need to sustain direct hits from heavy armor/concrete piercing ground weapons and near misses by 1.1-ton aerial ordnance without loss of structural integrity or major damage to personnel and equipment inside. To develop the best type of shelter, this study analyzed each threat separately and quantitatively. (The threat for the AUTODIN Switch Facility was limited to aerial ordnance falling no closer than 75 ft from the facility.) The analysis of these primary threats is summarized below.

1. Heavy armor/concrete piercing projectiles. These projectiles are very effective in perforating armor plate and reinforced concrete. The projectiles have a tough hardened alloy nose to withstand the high impact stresses and to distribute them over the projectile's forward body. Projectiles typically are fused with delayed action inertia-type base fuses that detonate the explosives after maximum penetration has been achieved. Approximately 15 percent of the projectile weight is highly explosive. Oblique impact decreases penetration and causes the projectiles to ricochet. Based on the available data, the Soviet 8.02-in. concrete penetrating artillery round weighing about 220.7 lb and containing about 34.2 lb of TNT was selected by DCA as the most logical threat. Rocket-assisted projectiles are believed to be under development for some of the artillery weapons which would greatly extend these weapons' velocity and range capabilities. however, they were not considered in this analysis.

2. Aerial ordnance. There are several types of highly explosive (HE) bombs such as general purpose, light case, armor piercing, semiarmor piercing, and fragmentation. General purpose (GP) bombs are designed for general destruction by blast and fragmentation. They will perforate light reinforced concrete and thin armor. After penetrating the earth, they will cause considerable damage to nearby structures due to the confined explosion. Light case (LC) bombs contain a larger percentage of HE and, consequently, their cases readily deform upon striking resistant materials, their main damage results from blast. Armor piercing (AP) bombs have heavy cases that resist deformation when striking heavily protected targets such as protective structures. Semiarmor-piercing (SAP) bombs have characteristics similar to AP bombs; however, they are not as effective. The charge weight ratios for HE bombs are approximately as follows: GP 50 percent; LC 75 to 80 percent, AP 5 to 15 percent, and SAP 30 percent. Fragmentation bombs contain only enough explosives to fracture their case and cause maximum velocity of the fragments. The 1.1-ton GP bomb was selected as the most logical threat and it was assumed to contain 1103 lb of TNT.

Approach

The rest of this report is organized into five sections that describe the development process and the case study.

Section B describes the basic requirements and initial conceptual designs for the Transportable Unit Storage Shelter, the Reconstitutional Package Storage Shelter, and the Operational Shelter. While developing this section, design alternatives were considered, evaluated, and selected for use in the conceptual design and cost estimate. Rectangular cross section structures of cast-in-place concrete were selected as baseline design.

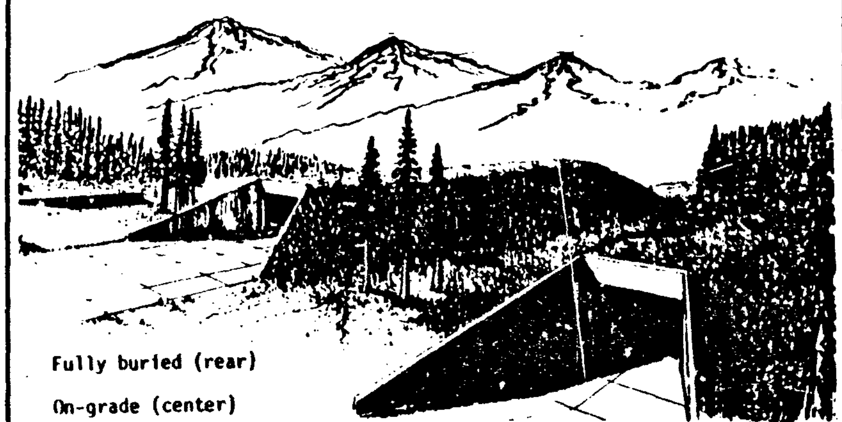
Section C describes baseline buildings using a preengineered metal structure as the unhardened example and a standard ammunition igloo for the semihardened example. The concepts were developed to provide a comparative basis for addressing a "low first cost" criteria. Neither building could meet the threat definition nor could they be modified easily to provide the needed hardness. The igloo would provide a low level of protection, however, and could be considered for use in some areas. Buildings can be constructed at grade and mounded, partially buried and mounded, or totally buried. The totally buried building was used in the comparative analysis.

Section D addresses several construction alternatives, each designed to reduce the onsite construction time or the skilled labor demands. Two alternatives specifically discussed for the operational shelter would have limited usefulness for storing truck-mounted equipment. The quality of space provided also varies among the alternatives, which may be a consideration in the final selection of building configuration and construction technique.

Section E presents general explanations of the design method and construction cost estimates together with the major underlying assumptions. The important findings of the design and cost estimating aspects

of this investigation are summarized. Also summarized are alternative construction concepts that satisfy the specified performance criteria for the various shelter types. The planner is completely responsible for selecting the most suitable shelter concept and construction technique at a specific geographical location.

In Section F, the least-cost alternatives developed in Sections D and E are applied to an AUTODIN Switch Facility with a limited threat definition and different operational requirements. Facility configurations and cost estimates are presented.



Fully buried (rear)

On-grade (center)

Semiburied (front)

FIGURE A-1. GENERAL APPEARANCE OF SHELTERS.

B1
RECONFIGURATION STORAGE SHELTER

function

To store truck-transportable DCS communication units in a way that enables them to survive attack and be available for reestablishing the communication network after the complete loss of unhardened communication facilities.

policy/sop

1. DCS has prepositioned communication equipment in Europe for reestablishing its communications network after initiation of hostilities and loss of existing unhardened facilities. Facilities are needed to provide a level of protection to the equipment greater than that provided in the motor pools, warehouses, and aircraft hangars.

2. No provisions will be made in the shelter for housing personnel. During an attack, if personnel should be present, space around the vehicles could be used for shelter; but life support systems and facilities are not required.

3. Site security will be external to the shelter and will be installed and monitored by others (i.e., personnel other than those responsible for building operation).

4. The communication equipment will not be operated in the shelter during or after the attack. There is no secondary mission for the shelter after the vehicles have been removed.

5. Systems should be provided by others to monitor and manage equipment in the shelter from a remote location.

6. If needed, unprotected power generation equipment can be provided to back up the base power supply. However, exposed components should be considered sacrificed during the attack and unusable afterwards. Power must be provided for opening the blast doors.

7. No effort will be made to camouflage the shelters' location.

issues and assumptions

1. Siting

Shelters should be located away from primary targets (e.g., aircraft, runways, weapon systems, ammunition dumps) to reduce the possibility of collateral damage from the attack. It has been assumed that the shelters are not prime targets and will be subjected only to warheads intended for other targets. Shelters may be located on- or off-post as needed to provide adequate separation from prime targets. If located off-post, the cost of providing and maintaining security must be considered in planning.

Shelter concealment has not been considered because (1) construction can be observed easily by satellite, and (2) the large, paved area needed for maneuvering vehicles in front of the shelter is highly visible.

Depending on the terrain, the shelter can be constructed either on the surface and mounded, partially buried and mounded, or totally buried. If possible, it should be sited to provide an entrance that slopes away from the shelter. This sloping entrance would help keep debris from accumulating on the entrance pavement, maintaining a clear area for when the equipment must be removed and put into operation. Advantage should be taken of the land's natural contour. Foundation drainage is required in most configurations to control groundwater. Use of tunnels in mountainous areas should be considered.

2. Access

Transport cabs and trailers can be backed into one long garage or side-by-side into two garages. Also, vehicles can be stored using either a "drive-through" configuration or an alternative single-access drive that would require backing-in for storage. Rapid mobilization requires that all vehicles be headed-out while in storage. The drive-through configuration may simplify the vehicles' movement and eliminate the need for backing into the long shelter. However, the drive-through configuration would require a second vehicular entrance into the shelter complete with a large blast door, extended roofline to protect the door, and entrance pad with a roadway connecting it to the other entrance. The one long shelter configuration was selected for this comparative analysis as being the most cost-effective (Figures B1-1 and B1-2).

Equipment shelter floors will be sloped to drain and constructed with depressed wheel tracks for guiding trailers as they are backed into the shelter. Cover plates will be provided to cover the tracks in the front section of the shelter to simplify movement of personnel and the portable generators (Figures B1-3 through B1-5).

SECTION B BASIC DESIGN

issues and assumptions

3. Primary mechanical systems and the need for emergency power

Each shelter shall have environmental control equipment. Base electrical power will be the shelter's main power source. Emergency and back-up power will be provided by a portable generator using an external connector. Power requirements are limited to maintaining the environment, opening the blast doors, and providing minimal lighting after attack. One portable generator could serve several shelters located on an installation. The stored equipment is relatively insensitive to temperature changes; moreover, since the shelter will be earth-covered, it should experience very little temperature change from the weather. For these reasons, the stored equipment would not be damaged if the power supply were interrupted over an extended period.

4. Security

It has been assumed that project planners will satisfy security requirements and, thus, such information has not been included in this comparative analysis.

activities

1. Driving in equipment initially.
2. Making the equipment accessible for periodic maintenance.
3. Monitoring humidity and temperature.
4. Maintaining and installing accessories.

personnel

1. Equipment maintenance team.
2. Inventory personnel.
3. Vehicle drivers.

equipment

1. Simple HVAC unit with heating and dehumidification capability.
2. Separate control for ventilation air.
3. Humidity and temperature instruments.
4. Portable electronic testing equipment on movable carts.

requirements	criteria	commentary
1. Adequate space.	1. Shelter must be sized to house the truck-mounted equipment and to provide adequate clearance for moving the truck in and out of the shelter. Space must be provided around the vehicles to allow maintenance personnel access to the equipment.	
2. Structure.	2. The shelter should be semihardened to withstand direct hits from at least two HE artillery rounds and near misses of bombs described under Threat definition (Section A in this document). These warheads would be falling outside their primary targets and would come near the communications shelter by accident.	
3. Openings.	3. One large vehicular blast door on a hanger-type sliding unit and a separate personnel-size sliding blast door must be provided. The personnel door would provide access to the equipment without opening the large (main) blast door.	
4. Ventilation system and humidity control.	4. A filter must be provided to remove dust from air in the shelter. Relative humidity control: 95 to 100 percent noncondensing at an ambient temperature of 100 degrees F.	
5. Illumination.	5. A 50-lux general light level must be provided with 110-V outlets for adjustable lights (for parts installation and/or inventory).	
6. Power.	6. A 110-V a.c. source must be provided for maintenance tools, 20 ft on-center throughout the shelter.	
7. Heating.	7. Shelter temperature must be maintainable at a level that will make it easy to start the truck. (The stored equipment can withstand temperatures of -50 to 155 degrees F without damage.)	
8. Survivability protection.	8. High-altitude electromagnetic pulse (HEMP) and chemical-biological-radiological (CBR) control equipment must be installed.	
9. Security fence.	9. An 8-ft-high chain-link fence with three strands of barbed wire, as a minimum, will be provided by others.	
10. Drainage ditches.	10. Cross-overs for drainage ditches must be provided so that all areas are readily accessible.	
11. Pavements.	11. Pavements and other site elements must be laid out to provide for the turning radius (35 ft) of the vehicle(s) stored.	

guidance

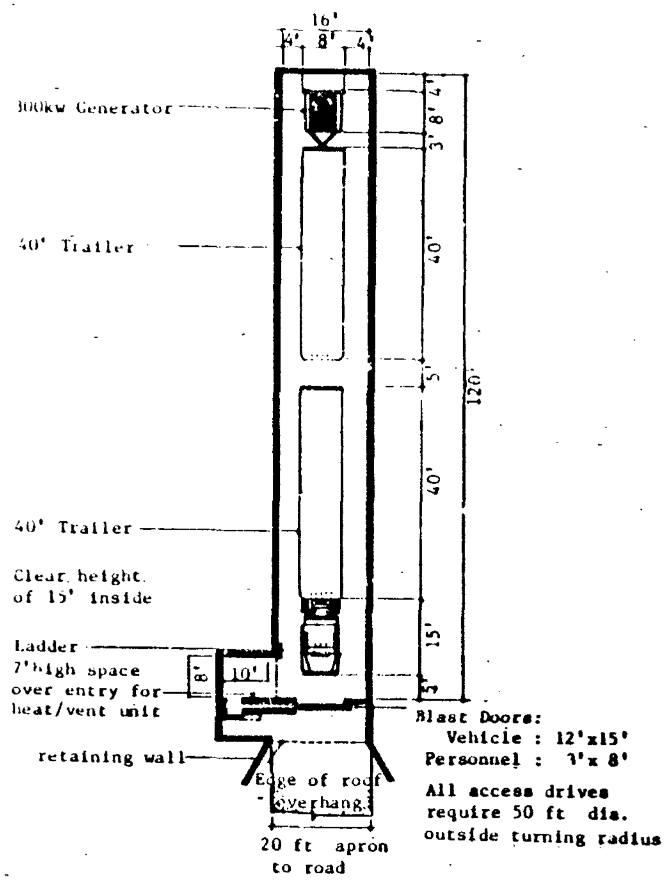


FIGURE B1-1. FLOOR PLAN--TRANSPORTABLE UNIT STORAGE SHELTER.

guidance

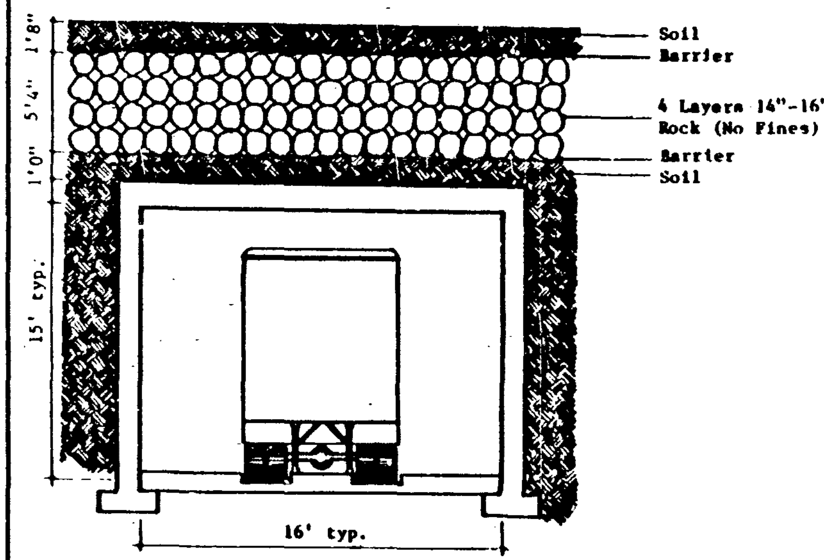


FIGURE B1-2. SHELTER SECTION.

guidance

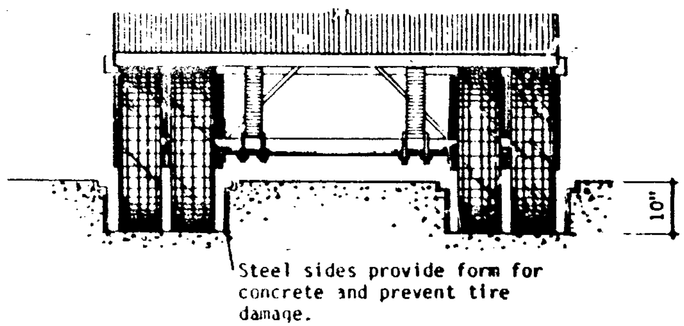


FIGURE B1-3. FLOOR TRACK SECTION.

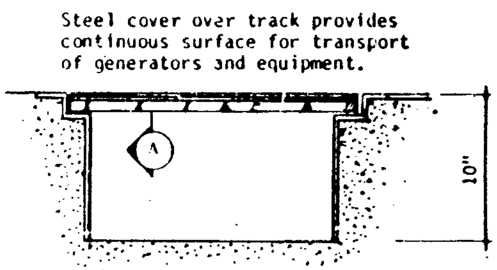


FIGURE B1-4. FLOOR TRACK DETAIL.

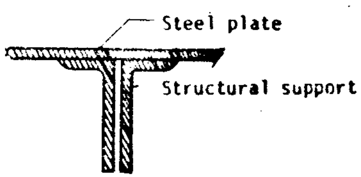


FIGURE B1-5. SECTION THROUGH TRACK COVER.

systems

1. Environmental control system

Storage shelter requirements affect the environmental control system in two ways. First, the exterior environment's influence on the interior is narrowed through the insulating effect of the earth cover. Second, limited activities are expected to be performed in the conditioned space. The primary load is assumed to be dehumidification in connection with storage.

2. Power systems

Commercial power will be used during the preattack period. There are no power requirements other than for battery-powered lighting during the attack period. To lower construction and operating costs, it was decided not to include a dedicated power generator in the shelter. In the post-attack period, a portable generator will supply power through an external connector to open the blast doors for vehicle removal.

B2 RECONSTITUTION STORAGE SHELTER

function

To store vehicle-mounted DCS communication equipment such that it will be protected from attack and accessible for reconstituting damaged communication centers to reestablish the network.

policy/sop

1. DCS has prepositioned communication equipment in Europe for use in reestablishing its communications network after initiation of hostilities and loss of existing unhardened facilities. Facilities are needed to provide a level of protection to the equipment greater than that provided in the motor pools, warehouses, and aircraft hangars.

2. No provisions will be made for housing personnel in the shelter. During an attack, if personnel should be present, space around the vehicles could be used for shelter, but life support systems and facilities are not required.

3. Site security will be external to the shelter and installed/monitored by others.

4. The communication equipment will not be operated in the shelter during or after the attack. The shelter has no secondary mission after the vehicles have been removed.

5. Systems should be provided by others to remotely monitor and manage the equipment installed in the shelter.

6. If needed, unprotected power generation equipment can be provided as a backup to base power. However, exposed components should be considered sacrificed during the attack and unusable afterwards. Power must be provided for opening the blast doors.

issues and assumptions

1. Siting

Shelters should be located away from primary targets (i.e., aircraft, runways, weapon systems, ammunition dumps) to reduce the possibility of collateral damage from attack. It has been assumed that the shelters are not prime targets and will be subjected only to warheads intended for other targets. Shelters may be located on- or off-post as needed to provide adequate separation from prime targets. If located off-post, the cost of providing and maintaining security must be considered in planning.

Shelter concealment has not been considered because (1) construction can be observed easily by satellite, and (2) the large paved area needed for maneuvering vehicles in front of the shelter is highly visible.

Depending on the terrain, the shelter can be constructed either on the surface and mounded, partially buried and mounded, or totally buried. If possible, the shelter should be sited to provide an entrance that slopes away from the shelter. This sloping entrance would help keep debris from accumulating on the entrance pavement, maintaining a clear area for when the equipment must be removed and put into operation. Advantage should be taken of the land's natural contour. Foundation drainage also is required in most configurations to control groundwater. Consideration should be given to using tunnels in mountainous areas.

2. Access

Trucks and trailers will be backed into the shelter. A "drive-through" configuration may simplify the vehicles' movement and eliminate the need for backing into the shelter. However, the drive-through configuration would require a second vehicular entrance into the shelter complete with a large blast door, extended roof to protect the door, and entrance pad with a roadway connecting it to the other entrance. The single-entrance configuration was selected for this comparative analysis as being the most cost-effective (Figure B2-1).

The shelter floor will be sloped to drain and constructed with depressed wheel tracks for guiding the truck as it backs into the shelter. Cover plates will be provided to cover the tracks in the front section of the shelter to simplify personnel movement.

3. Primary mechanical systems and the need for emergency power

Each shelter shall have environmental control equipment. Base electrical power will be the shelter's main power source. Emergency and back-up power will be provided by a portable generator using an external connector. Power requirements are limited to maintaining the environment, opening the blast doors, and providing minimal lighting after the attack. One portable generator could serve several shelters located on an installation. The stored equipment is relatively insensitive to temperature changes. Moreover, since the shelter will be earth covered, it should experience very little temperature change from weather. For these reasons, the stored equipment would not be damaged if the power supply were interrupted over an extended period.

issues and assumptions

4. Security

It has been assumed that project planners will satisfy security requirements and, thus, this information has not been included here.

activities

1. Driving in equipment initially.
2. Making the equipment accessible for periodic maintenance.
3. Monitoring humidity and temperature.
4. Installing and maintaining accessories.

personnel

1. Equipment maintenance team.
2. Inventory personnel.
3. Vehicle drivers.

equipment

1. Simple HVAC unit with heating and dehumidification capability.
2. Separate control of ventilation air.
3. Humidity and temperature instruments.
4. Portable electronic testing equipment on movable carts.

requirements	criteria	commentary
1. Adequate space.	1. Shelter must be sized to house the truck-mounted equipment and to provide adequate clearance for moving around the vehicle to allow maintenance personnel access to the equipment.	
2. Structure.	2. Shelter should be semi-hardened to withstand direct hits from at least two HE artillery rounds and near misses of bombs described under Threat definition. These warheads would be falling outside their primary targets and come near the communications shelter only by accident.	
3. Openings.	3. One large vehicular blast door on a hanger-type sliding unit and a separate personnel-size sliding blast door must be provided. The personnel door will provide access to the equipment without opening the large (main) blast door.	
4. Ventilation system and humidity control.	4. A filter must be installed to remove dust from the air in the shelter. Relative humidity control should maintain a 95 to 100 percent noncondensing environment at an ambient temperature of 100 degrees F.	
5. Illumination.	5. A 50-lux general light level must be provided with 110-V a.c. outlets for adjustable lights (for parts installation and/or inventory).	
6. Power.	6. Supply 110-V a.c. power for maintenance tools, 20 ft on-center throughout the shelter.	
7. Heating.	7. Shelter temperature must be maintained at a level that will make it easy to start the truck. (Stored equipment can withstand temperatures of -50 to 155 degrees F without damage.)	
8. Survivability.	8. HEMP and CBR control equipment must be installed.	
9. Security fence.	9. An 8-ft-high, chain-link fence with three strands of barbed wire, as a minimum, will be provided by others.	
10. Drainage ditches.	10. Cross-overs for drainage ditches must be provided so that all areas are readily accessible.	
11. Pavements.	11. Pavements and other site elements must be laid out to provide for the turning radius (35 ft) of the stored vehicle.	

guidance

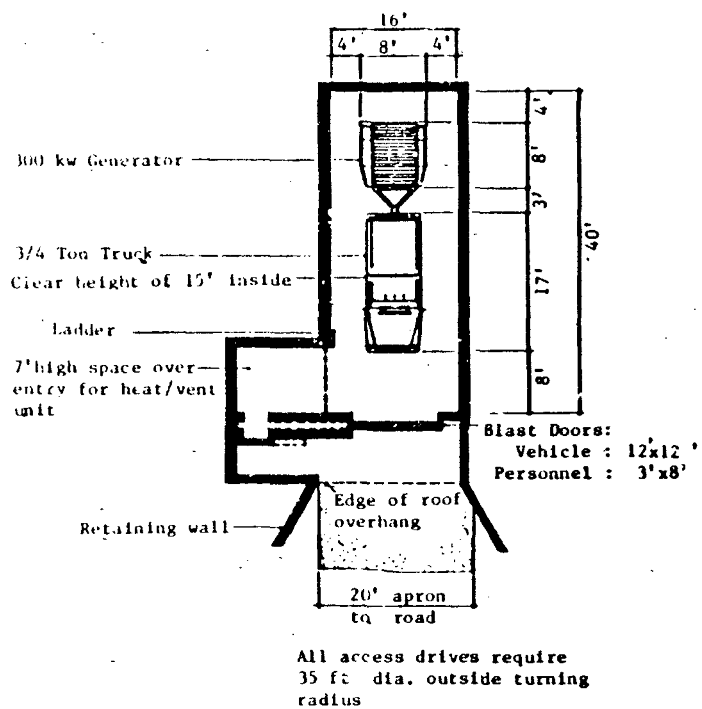


FIGURE 82-1. FLOOOR PLAN--RECONSTITUTIONAL PACKAGE STORAGE SHELTER.

systems

1. Environmental control system.

Storage shelter requirements affect the environmental control system in two ways. First, the exterior environment's influence on the interior is narrowed through the insulating effect of the earth cover. Second, the conditioned space is expected to support only limited activities. The primary load is assumed to be dehumidification in connection with storage.

2. Power systems

Commercial power will be used during the preattack period. The shelter has no power requirements, other than for battery-powered lighting, during the attack period. To lower construction and operation costs, it was decided not to include a dedicated power generator in the shelter. In the postattack period, a portable generator will supply power through an external connector to open the blast doors for vehicle removal.

B3 DCS OPERATIONAL SHELTER

function

To provide a semihardened communications operational center that can be used to reestablish and operate the DCS communications network in areas subject to attack.

policy/sop

1. The operational shelter will be used either in conjunction with a Transportable Unit Shelter or in a stand-alone configuration.
2. Space will be provided for a crew of 25 plus sanitary facilities, water supply, and power supply to support operations during base power interruptions.
3. Site security will be external to the facility and installed/monitored by others.
4. Provisions will be made for maintaining an environment that would support life in the operational space for at least 4 hours without external assistance.
5. This comparative analysis does not consider the design, siting, and construction of an antenna.
6. The shelter should provide for the command and communication circuits from the unhardened communication center as well as circuits to an antenna located at some remote site.
7. The base power supply will be the shelter's primary source. An onsite power supply will be provided for postattack operations.

activities

1. Establishing workstations.
2. Installing communication equipment initially, including integration and checkout.
3. Filling water and fuel storage tanks.
4. Checking backup power.
5. Testing environmental control equipment.
6. Monitoring internal environment and status of storage tanks.
7. Performing periodic operational checks.
8. Maintaining equipment.

personnel

1. Equipment installers.
2. DEH personnel to fill and maintain storage tanks.
3. Inventory personnel.
4. Equipment test, operation, and evaluation personnel.
5. DEH building equipment maintenance personnel.

equipment

1. Heating, ventilating, and A/C equipment.
2. Temperature and humidity sensors and controls.
3. Communication equipment.
4. Portable electronic testing equipment on movable carts.
5. Fire alarms and sensors.
6. Security system components.
7. Water pumps and supply equipment.
8. Sanitary lift station.
9. Fuel storage tank and distribution.

issues and assumptions

1. Siting

Shelters should be located away from primary targets (e.g., aircraft, runways, weapon systems, ammunition dumps) to reduce the possibility of collateral damage from attack. It has been assumed that the shelters are not prime targets and will be subjected only to warheads intended for other targets. Shelters may be located on- or off-post as needed to provide adequate separation from prime targets. If located off-post, the cost of providing and maintaining security must be considered in planning.

Shelter concealment has not been considered because (1) construction can be observed easily by satellite, and (2) the large paved area needed for maneuvering vehicles in front of the shelter is highly visible.

Depending on the terrain, the shelter can be constructed either on the surface and mounded, partially buried and mounded, or totally buried. If possible, the shelter should be sited to provide an entrance that slopes away from the shelter. This sloping entrance would help keep debris from accumulating on the entrance pavement, maintaining a clear area for when the equipment must be removed and put into operation. Advantage should be taken of the land's natural contour. In addition, most configurations require foundation drainage to control groundwater. Consideration should be given to using tunnels in the mountainous areas.

2. Facility configuration

The operational shelter (Figures B3-1 through B3-5) has been assumed to be an integral part of the equipment shelter to reduce construction cost and still meet the endurability criteria. The two spaces share a common wall; artillery rounds striking the center of the building would hit near the center wall. Consideration was given to constructing two buildings at least 10 ft apart and connected by two tunnels--one for equipment and personnel movement, and the other just for personnel. This design would require additional excavation and structural walls, compacted backfill between the two structures, and a much larger rock rubble blanket. On the basis of cost and extended construction time, the two-shelter concept was dropped in favor of an integrated shelter.

The integrated shelter should be designed to present a flat roof, with the difference in interior vertical ceiling heights reflected in the floor elevations. Steps inside the operators' shelter will be used to compensate for the difference in floor elevations. Ramps were considered and then rejected on the basis that they require additional floor space. Ramps would make equipment movement easy, but the benefit was not worth the cost in floor space. To facilitate equipment movement, the equipment room floor should be placed at the same level as the equipment shelter with a roll-up door used to separate the two spaces.

issues and assumptions

Blast doors for personnel and vehicles (Figure B3-2) will be designed to withstand overpressures and debris from the specified threat. These horizontal sliding doors will be protected in structural concrete pockets. The vehicular door will operate electrically. The roofline will be extended to protect the doors from direct hits and to provide weather protection for the generator sets in their operating positions. The blast doors' design will consider the reflected effect of blast within the enclosed area.

Personnel doors will connect the equipment and operational shelters. Fire-rated doors will be used to isolate the two areas.

Vents with fire dampers will be provided in the wall between the operational and equipment spaces. The vents will allow air to circulate from the operational space into the equipment space, then to the outside through a blast valve. In case of fire, the dampers will close to prevent smoke from spreading between the two areas.

The floors will be treated with a sealant to reduce dust and a wearing surface will be provided for the operators' comfort. Raised floors are not required. A dropped ceiling will be used to cover the overhead air handling units, chilled water lines, and ductwork.

The equipment shelter floor will be sloped to drain and constructed with depressed wheel tracks to guide trailers being backed into the shelter. Cover plates will be provided to cover the tracks in the shelter's front section to simplify movement of personnel and generators.

The total length of operator's shelter will exceed that of the equipment shelter. To maintain a rectangular configuration and to minimize cost, the operators' shelter will be designed to wrap around the end of the equipment shelter. As a stand-alone shelter, the most economical configuration appears to be a 40-ft-wide building with a center load-bearing wall (see Figure B3-12, later).

The exterior wall and roof surfaces will be waterproofed with a sprayed-on material or a single-ply membrane and covered with insulation board before backfilling.

3. Access

Personnel access to the operators' space will be through the equipment space in the integrated shelter. Decontamination of personnel entering the shelter is not a consideration. An emergency exit to grade will be provided (Figure B3-6).

issues and assumptions

The emergency exit will be placed behind the equipment shelter to take advantage of the intersection of two structural walls. The tube extending to the surface will be filled with sand to ensure the continuity of the protective layer over the shelter. To use, personnel would release the lower door allowing the sand to fall into the equipment shelter, climb through the exit, and release the weather cap. Two wall-hung ladders will be provided to allow personnel to release the inner door from one side and not be subjected to the load of falling sand.

The "drive-through" configuration may simplify the movement of vehicles and eliminate the need for backing into the long shelter. However, the configuration would require a second vehicular entrance into the shelter complete with a large blast door, extended roof, entrance pad, and a roadway connecting it to the other entrance. The single entrance configuration was selected for this comparative analysis as being the least expensive. Figure B3-7 shows alternative entryways for this configuration.

4. Electrical power

The shelter will require power for operations and environmental control during the pre and postattack periods. The base power system will be the shelter's main source. If the communication equipment is not to be operated other than for periodic tests, the load expected will be that for environmental control. During an attack, all operations would cease and battery-operated emergency lights would provide illumination after base power is lost. All operations will cease during the attack until the blast doors can be opened, the generators moved to outside and brought online, and the communications network reestablished. Portable diesel engine generator sets stored in the equipment shelter will provide postattack power. The generators will be moved to the exterior operating space, connected to the fuel and power supply lines, and put into operation. The stored equipment is relatively insensitive to temperature changes that could be experienced inside the shelter due to extended power outages.

The estimated power requirement is 520 kW based on the 300-kW load criteria plus the environmental control system. This requirement can best be met by two 300-kW portable diesel generator sets. A buried fuel storage tank with an 8400-gal capacity will provide for 7 days of continuous operations. A single 600-kW generator was rejected because:

a. It has lower availability/reliability; with two generators, operations could continue on a limited basis if one of the generators were to fail.

b. During periods of low power requirements, the two 300-kW generators could be used to supply a wide range of energy levels efficiently. Since generators should not be operated at less than 60 percent of their rated capacity, the 600-kW generator would be severely limited in supplying low energy levels.

issues and assumptions

Generators should be trailer-mounted to simplify over-the-road movement and maintenance and to provide the flexibility to move them to other shelters if needed.

The buried fuel tank will be protected by the same soil rock layer protecting the shelter. Tanks will be situated to provide a gravity feed to the generator operating area and to prevent shelter damage if they should be ruptured during attack

Alternative energy sources were considered before the diesel generator sets were selected. The need to survive the attack eliminated systems that depend on collectors and other structures that are above ground and impractical to harden. Since postattack operations do not require hardened power supplies, the need for some of the more expensive hardenable power sources was eliminated. Using a power supply that can be moved outside for operation also eliminated the need for hardened air intake and exhaust structures and for an engine cooling system.

5. Environmental control

During the preattack nonoperational period, minimal HVAC functions will be provided to control the humidity inherent in buried shelters. Operational cooling during pre- or postattack will be provided by a 100-ton groundwater-cooled chiller, a chilled water distribution system, and a distributed system of air handling units. Water will be taken from one well, passed through the chiller, and returned to the ground through a second well. Two wells will provide a more reliable water source for the shelter and, in case of pumping problems with one well, cooling water could be wasted to the sewage lagoon or just to the outside.

The mechanical equipment room will have an air handling unit (AHU) and distribution system to meet low cooling loads and distribute outside air throughout the operational space. Three chilled-water AHUs will be located above the ceiling in the operational space to carry the remainder of the load. Distributed AHUs could be floor-mounted if space is available. The four AHUs can be used to meet cooling requirements efficiently as the loads vary.

Outside air will be ducted into the shelter at 375 cfm through a blast valve and CBR filter. This approach will cause a positive pressure in the operational space to reduce infusion of contaminants from the equipment space. To reduce operating costs, an outside air system rated at 10,000 cfm will also be provided for total cooling by outside air. The system will be provided with a blast valve but no CBR filter. The air will be exhausted through a blast valve by the pressure differential from the equipment shelter.

During the button-up period, no environmental equipment will operate; however, it has been calculated that the operational crew could easily survive more than 16 hours in the shelter without additional outside air or use of the mechanical equipment.

ues and assumptions

The mechanical equipment room will contain one AHU with a CBR filter, chiller, chilled water circulation pumps, compressor for control systems, and the sanitary sewage lift station. A roll-up door will be provided between the equipment shelter and the mechanical room to simplify initial installation of equipment and maintenance (Figure B3-8).

6. Water and waste disposal

Water will be supplied from a ground well and pressure tank to meet both potable and cooling water requirements. Cooling water will be returned to the ground through a second well. Two wells will provide a secondary water source that can be used if a failure occurs in the primary system. Cooling water will be wasted to the outside through the wastewater system if it is not possible to return it to the ground through one of the wells.

Wastewater will be discharged to the sewage lagoon through the lift station located in the mechanical equipment room (see Figure B3-9 for siting the lagoon). Successful operation of the facility depends on being able to discharge waste. Therefore, the lift station should be placed in the shelter for protection; an unprotected lift station located near the lagoon would require the gravity pipe to be buried deeply. After an attack, if the discharge pipe has been blocked (damaged or destroyed), the lift station will be used to pump waste to the surface through a flexible hose. The lagoon will be designed on the basis of the expected wastewater flow. However, if cooling water must be discharged through the system because of some problem, the lagoon may overflow until the problem can be corrected.

Flexible connections will be used in the piping systems near the building to reduce possible damage from ground shock (Figures B3-10 and B3-11).

7. Security

It has been assumed that project planners will satisfy security requirements and, thus, this information has not been included here.

Issues and assumptions

requirements	criteria	commentary
1. Adequate space.	1. Shelter must provide 100 sq ft per operator, plus sanitary facilities and mechanical space. There are no requirements for living quarters, rest areas, food storage/preparation, general storage, or maintenance.	
2. Structure.	2. Shelter should be semihardened to withstand the specified threat.	
3. Openings.	3. Shelter will have one emergency escape exit to the surface. Two personnel doors will be provided between the operational space and the equipment storage area for fire and environmental control. Two separate personnel entrances will be provided on the stand-alone shelter configuration for fire safety (Figures B3-12 through B3-14). Openings will be provided in the roof extending over the generator operating area to pass exhaust to the exterior, thus preventing a build-up of fumes in the entrance area.	
4. Ventilation system and humidity control.	4. A filter must be installed to remove dust from the air. Ventilation and humidity requirements will conform to existing criteria for operational spaces. A CBR filter will be provided in the ventilation air system for use during the button-up period. Openings will be provided (covered with fire dampers) between the major areas for air circulation.	
5. Illumination.	5. A 50-lux general light level must be provided with 100-V outlets for adjustable lights.	
6. Power.	6. A 300-kW supply is needed for all lighting, equipment operation, and environmental control equipment. Electrical outlets, 100-V a.c., will be provided for equipment on 10-foot centers throughout the shelter. Backup power will be provided by a portable generator. Energy needed to reject the waste heat, etc. will add approximately 300 kW, raising the needed power generation to 600 kW. Fuel storage and cooling system should be sized to support at least 7 days of continuous operations without external support.	
7. Heating and cooling.	7. The environment shall be maintained within the standard temperature range for the operational spaces. Ground loop or well water cooling systems should be considered.	

requirements	criteria	commentary
8. Survivability protection.	8. HEMP and CBR controls must be provided. Shelter must be capable of being totally buttoned up for 4 hours without a power source. The environment must be maintained to support personnel in a nonoperational mode during the button-up period.	
9. Security.	9. To be provided by others, depending on the situational requirements.	
10. Drainage.	10. Site must be well drained to control ground- and run-off water.	
11. Potable water.	11. Approximately 1125 gal of water are needed daily for the operators. The need to treat well water will vary by location.	
12. Sanitary waste removal.	12. Provisions must be made for safe disposal of sanitary waste.	

guidance

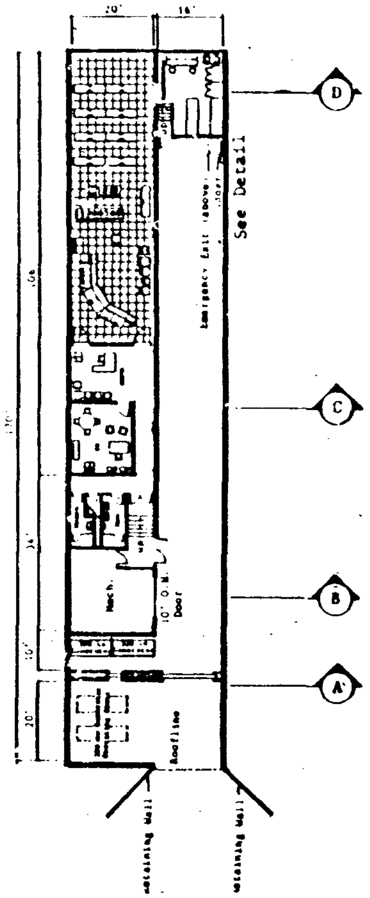


FIGURE B3-1. FLOOR PLAN--OPERATIONAL SHELTER.

guidance

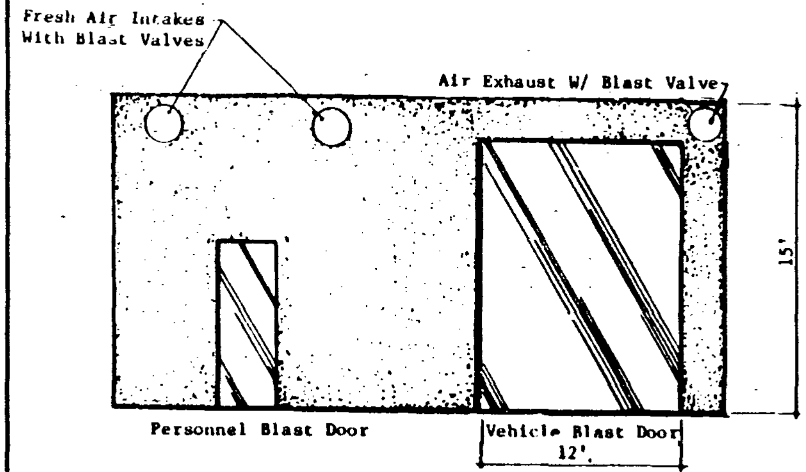


FIGURE B3-2. SECTION A-A.

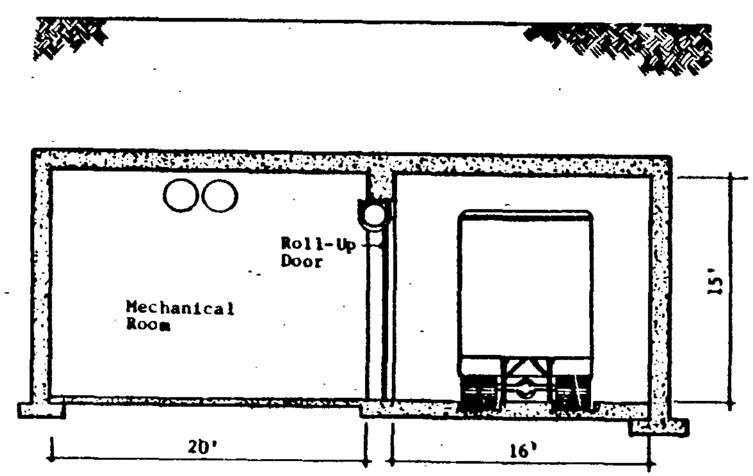


FIGURE B3-3. SECTION B-B.

guidance

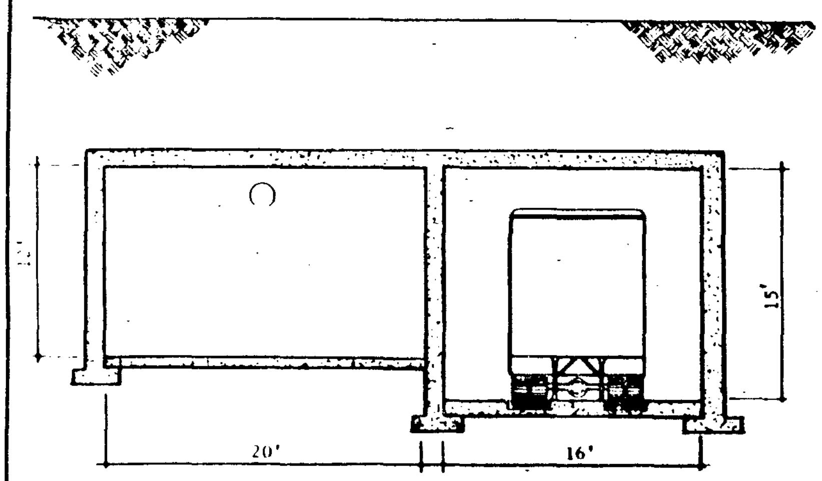


FIGURE B3-4. SECTION C-C.

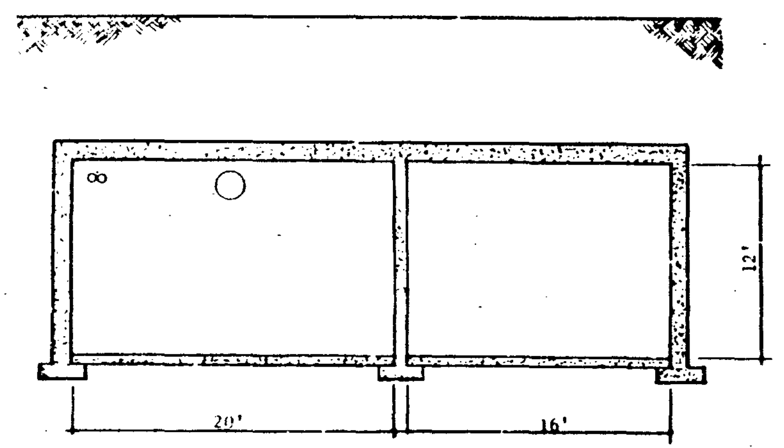


FIGURE B3-5. SECTION D-D.

guidance

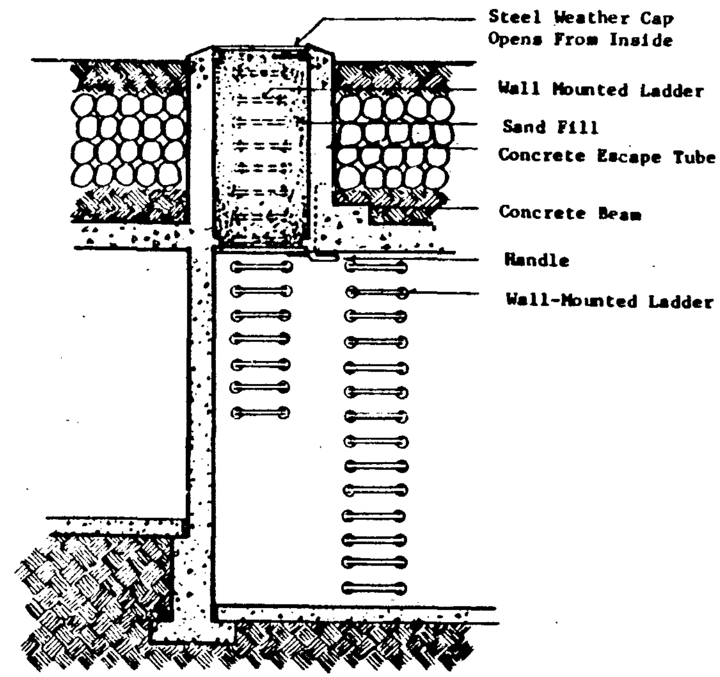
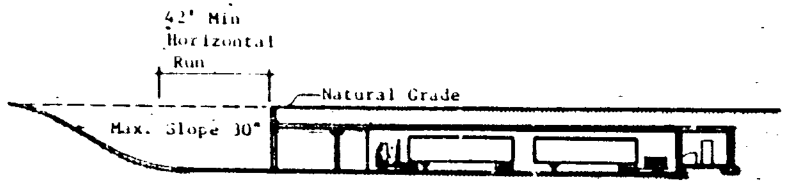
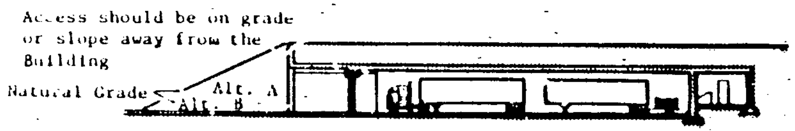


FIGURE B3-6. EMERGENCY EXIT DETAIL.

guidance



LONGITUDINAL SECTION ALTERNATIVE C



LONGITUDINAL SECTION ALTERNATIVES A & B

FIGURE B3-7. LONGITUDINAL SECTIONS.

guidance

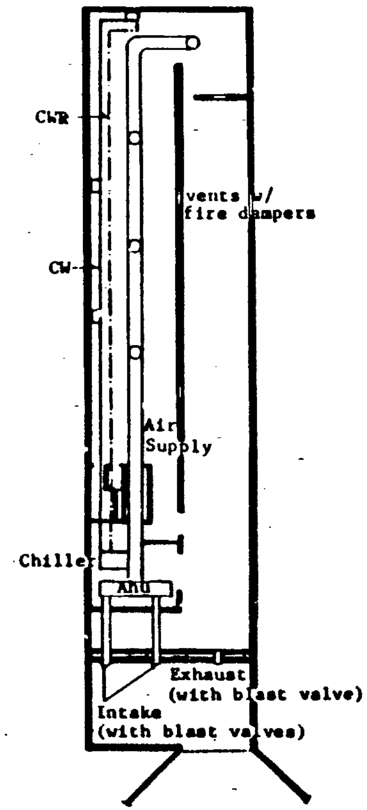


FIGURE B3-8. MECHANICAL PLAN.

guidance

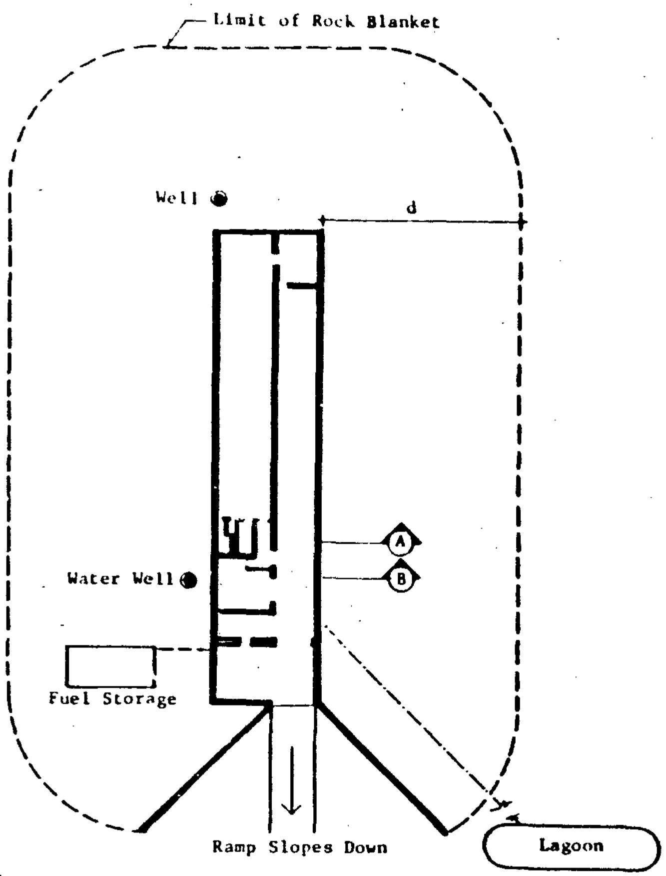


FIGURE B3-9. SITE PLAN.

guidance

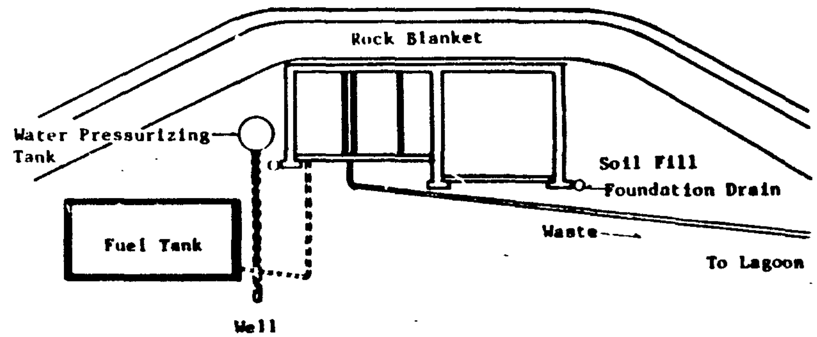


FIGURE B3-10. SECTION--MOUNDED CONSTRUCTION.

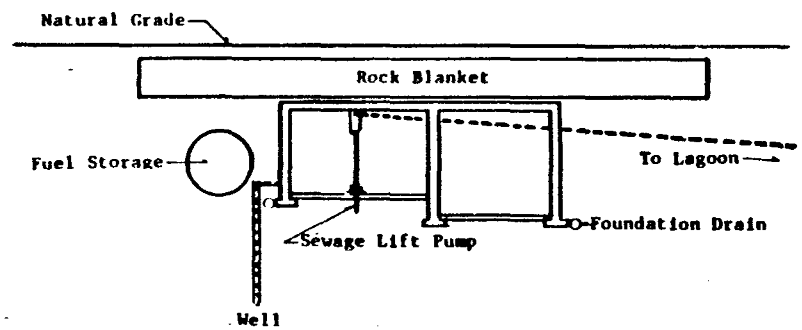


FIGURE B3-11. SECTION--BELOW-GRADE CONSTRUCTION.

guidance

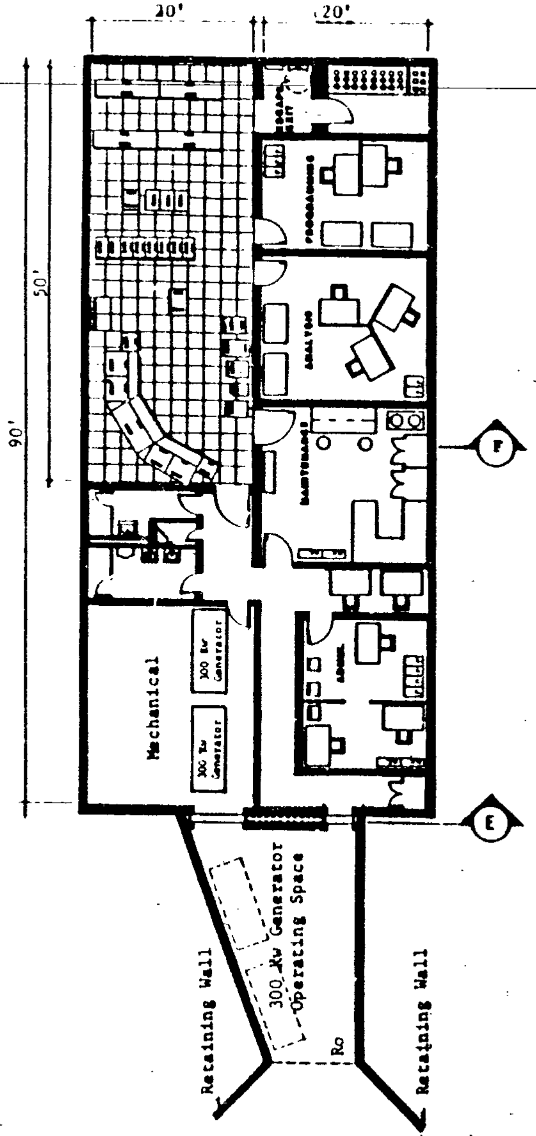


FIGURE B3-12. FLOOR PLAN--STAND-ALONE CONFIGURATION.

guidance

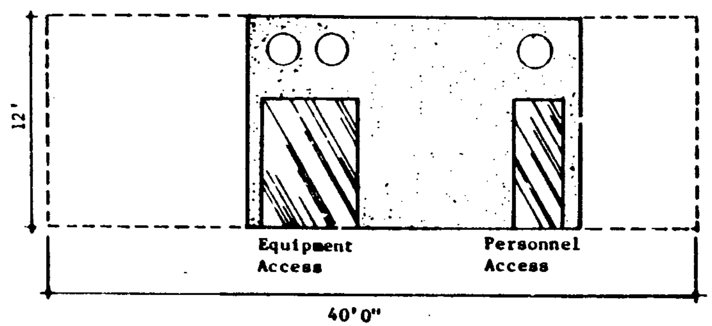


FIGURE B3-13. Section E-E.

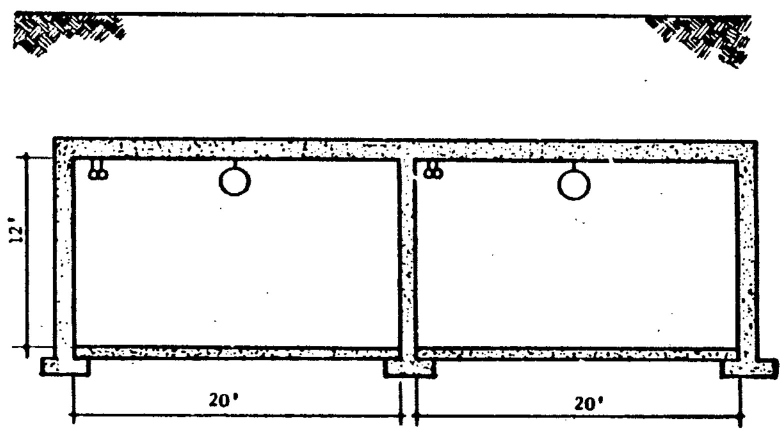


FIGURE B3-14. SECTION F-F.

guidance

guidance

1. Environmental control system

Burying a shelter greatly reduces the exterior environment's influence on the interior. The operational space will require an environment in the postattack period equal to any other communication space. The vehicle storage bay requires no environmental treatment.

2. Power systems

Commercial power will be used during the preattack period. The only power requirement during the attack period is for battery-powered lighting. Since the operational space will be used in the post-attack period, two portable generators should be provided. These generators will operate outside the shelter with weather protection only; however, hardened fuel storage will be required to support the generators.

SECTION C BASELINE CONSTRUCTION

guidance

Requirements

All facility concepts must be evaluated in terms of the four performance attributes by a comparison with conventional construction. For comparison, baseline descriptions were developed for two facilities representing different construction technologies. The first is a conventional preengineered, steel-framed, metal-sided building designed to protect the equipment from the weather. The other is a standard reinforced-concrete ammunition igloo with an exposed blast door. Neither facility would protect against the specified threat. The cost estimates are based on the rationale stated in Section E, ANALYSIS AND CONCLUSIONS.

C1 Baseline metal building

The building selected is a low, rigid-frame, preengineered steel structure manufactured and erected by several firms (Figure C-1). Figure C-2 shows a typical wall section. The structure has a reinforced concrete foundation and floor slab and a rigid steel frame with bents on 20-ft centers. The clear height is 15 ft and the width is 20 ft. The wall system is 26-gage factory-fabricated and -finished steel panels with 4 in. of insulation and vapor barrier. Interior surfaces are covered with 26-gage wall panels up to 8 ft high to protect the insulation. The roof is a 24-gage steel panel system with 6 in. of insulation covered with a vapor barrier. The personnel and vehicle doors are metal-clad and insulated.

guidance

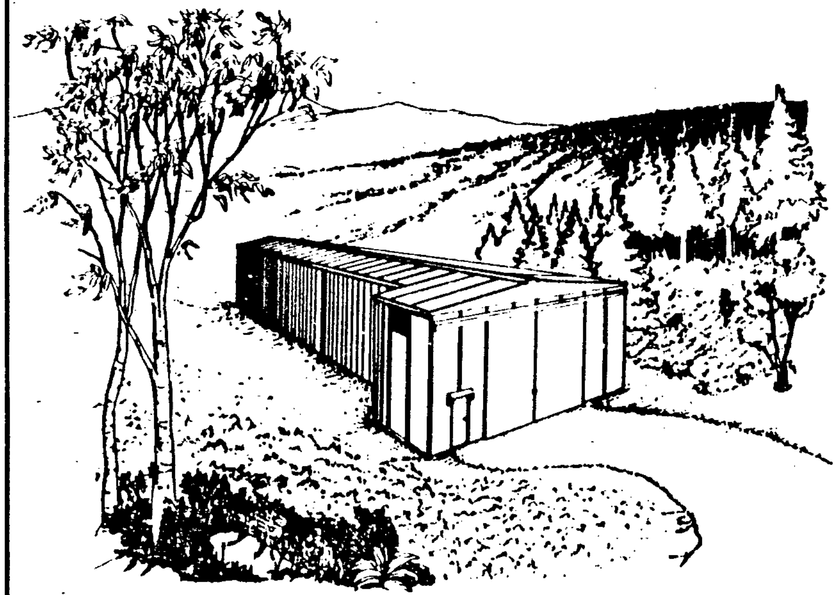


FIGURE C-1. ELEVATION--METAL BASELINE BUILDING.

guidance

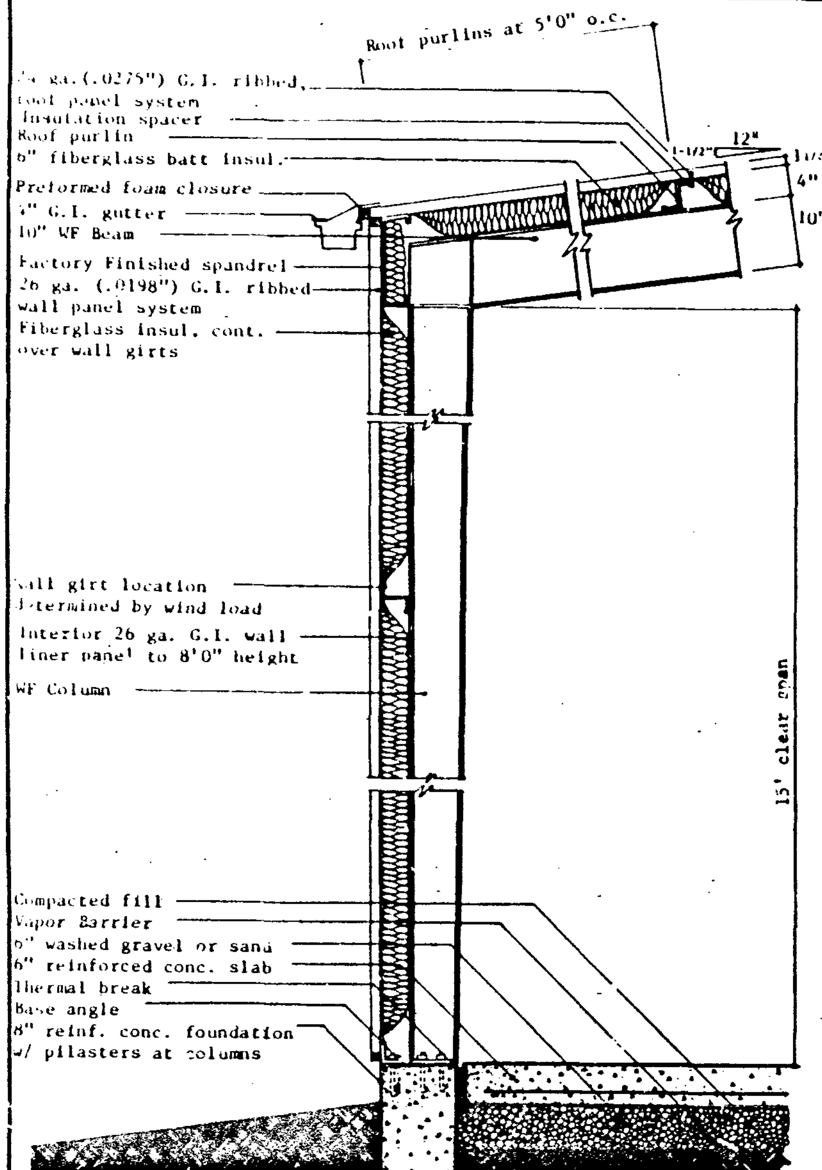


FIGURE C-2. WALL SECTION.

guidance

C2 Baseline concrete building

The standard ammunition igloo is constructed of cast-in-place reinforced concrete using reusable metal forms. One end wall is left exposed and contains the blast door. The igloo is designed to protect the stored ammunition from accidental detonation due to external causes and to limit the damage that could result if the ammunition were detonated inside the igloo. Embankments often are constructed across the road from the blast door to reduce the possibility of this door becoming a target for enemy fire and to limit the damage that could cause a detonation inside the igloo during vehicle loading/unloading activities (when the door is open). Three different siting conditions were considered. In Condition A, the igloo is constructed on-grade and mounded (Figure C-3). In Condition B, the igloo is partially buried and mounded (Figure C-4). In Condition C, the igloo is totally buried (Figure C-5). The structure was designed to carry little more than the weight of the earth cover and cannot withstand a major dynamic load.

Estimated costs for the shelters are summarized below. See the appendix for detailed cost estimates.

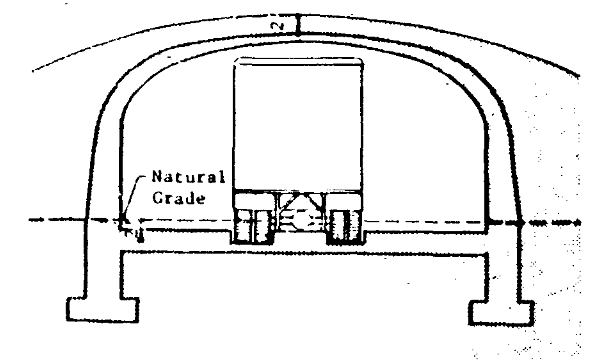
RECONSTITUTIONAL UNIT STORAGE (900 SQ FT)

	Total Cost	Unit Cost
Condition A	$259,000	$287.78
Condition B	$258,000	$287.67
Condition C	$257,000	$285.56

TRANSPORTABLE UNIT STORAGE (2500 SQ FT)

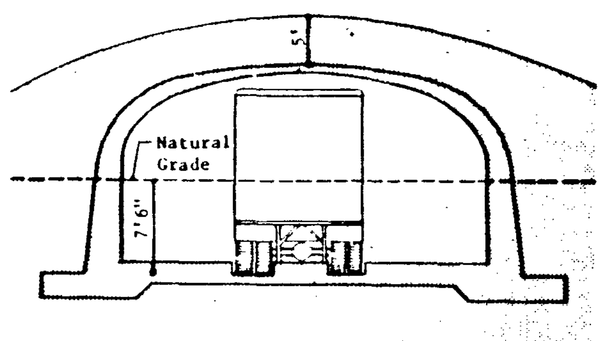
	Total Cost	Unit Cost
Condition A	$405,000	$162.00
Condition B	$405,000	$162.00
Condition C	$410,000	$164.00

guidance



ALTERNATIVE A

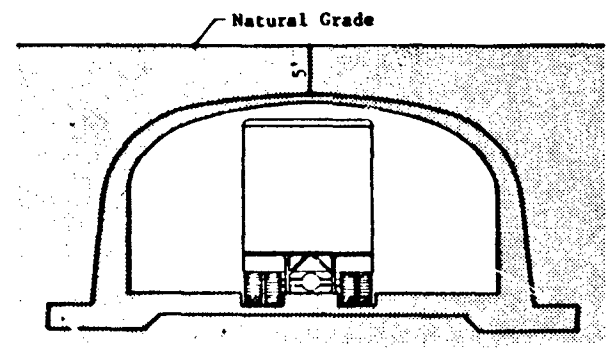
FIGURE C-3. ALTERNATIVE A--BASELINE CONCRETE BUILDING.



ALTERNATIVE B

FIGURE C-4. ALTERNATIVE B--BASELINE CONCRETE BUILDING.

guidance



ALTERNATIVE C

FIGURE C-5. ALTERNATIVE C--BASELINE CONCRETE BUILDING.

SECTION D
CONSTRUCTION ALTERNATIVES

Issues and assumptions

Requirements

Hardened and semihardened shelters are invariably constructed of concrete in various configurations using several forming techniques. This section identifies several alternative construction techniques that can be used to reduce both construction time and cost. These alternatives include conventional concrete mixes as well as fibrous concrete. Fibrous concrete replaces reinforcing steel bars with short steel fibers mixed into the concrete matrix. The short fibers give fibrous concrete much higher resistance to cracking; moreover, this material's performance does not depend on the bond developed between the matrix and reinforcing steel bars. Fibrous concrete can be placed in forms, pumped, or applied through shotcreting equipment.

D1 Shotcrete construction

Shotcreting techniques can reduce construction time. In conventional construction, shotcreting reduces the time it takes to deliver the concrete into the forms and simplifies placement that otherwise would require erection of ramps, etc., to move heavy loads. Using fibrous reinforced concrete could further reduce construction time by eliminating the need for reinforcing bars in the forms. Fibrous concrete can be pumped in a shotcreting operation or placed in mass using the same techniques commonly used in concrete construction. However, shotcreting requires special equipment that may not be readily available in all locations. In addition, fibrous concrete, though used in the United States, may be an unknown material in some locations. Finally, the ductility factor assigned to shotcrete is somewhat lower than that assigned to cast-in-place concrete, so that shotcrete would require additional structural thicknesses to provide equal protection.

D2 Precast construction

The shelter could be constructed of structural elements precast either onsite or in commercial casting yards and transported to the site. Elements would be cast horizontally to simplify the placement of reinforcing steel and allow entire panels to be cast in one operation. If they were constructed vertically, the shelter walls would require that concrete be placed in lifts with the lower concrete allowed to set before the remaining height could be placed. Precast techniques eliminate the need to construct all forms by producing standard precast elements. These elements require that adequate lifting equipment be onsite for lifting them into place. In addition, precast elements that must be truck-transported from offsite casting yards will be limited in weight and width. (The precast elements' weight may become a major problem as their thickness increases.)

Issues and assumptions

The primary weakness in this construction technique is the limited strength that can be developed in the connections. Wall-to-roof joints between precast concrete elements often are simple, but other joints are secured in place by welding together steel plates embedded in the surface of the elements. The joint's resistance to movement and rotation depends on the weld and on the plates' embedded anchors. The joint can be pinned together and stiffened with reinforcing steel bars in grouted holes (Figure D-1). However, with a lateral load, the joints will not react as a fixed joint and the wall will tend to deflect inward, causing joints to open. Roof units are keyed together to resist downward pressures (Figure D-2). These types of joints were assumed to be used in the precast concrete shelter considered in this analysis.

As an alternative technique for stiffening joints, the wall-to-roof joint could be stiffened to external lateral pressures by using a shoulder on the roof slab (Figure D-3) and a step in the floor slab. However, the shelter has not been designed to withstand internal pressure. Roof construction could also be stiffened by using precast concrete beam panels (Figure D-4) to avoid the inherent weakness of the keyed joint. Although these techniques would improve the structural joints, construction cost and time would increase with no major increase in the ductility factor.

Figures D-5 through D-7 show another type of connection--a pinned lap joint. Figures D-8 and D-9 illustrate keyed joints.

As an alternative to conventional precast construction, the shelter could be built of integral longitudinal segmental sections precast onsite. The section's length would be determined by its weight and the capacity of onsite cranes. Sections could be cast in reusable forms then lifted into place. They would fit together using a tongue-and-groove detail on the contacting surfaces. After all units are installed, a system of posttensioning tendons could be used to clamp the sections together. Figures D-10 through D-13 show details of this alternative concept. The wall panels could be cast horizontally on the foundation slab to minimize formwork and excavation.

guidance

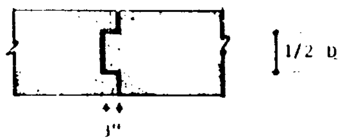


FIGURE D-2. ROOF SLAB JOINT.

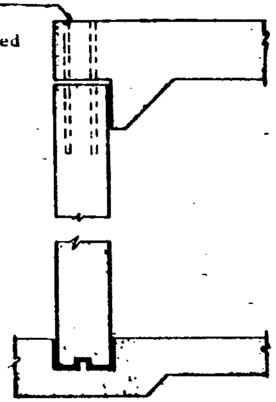


FIGURE D-3. PINNED SHOULDER JOINT.

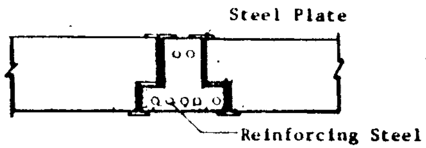


FIGURE D-4. BEAMS FOR PRECAST ROOF PANELS.

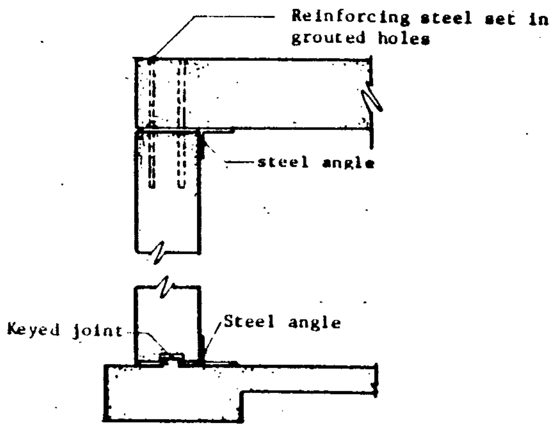


FIGURE D-1. PINNED PRECAST ELEMENTS.

guidance

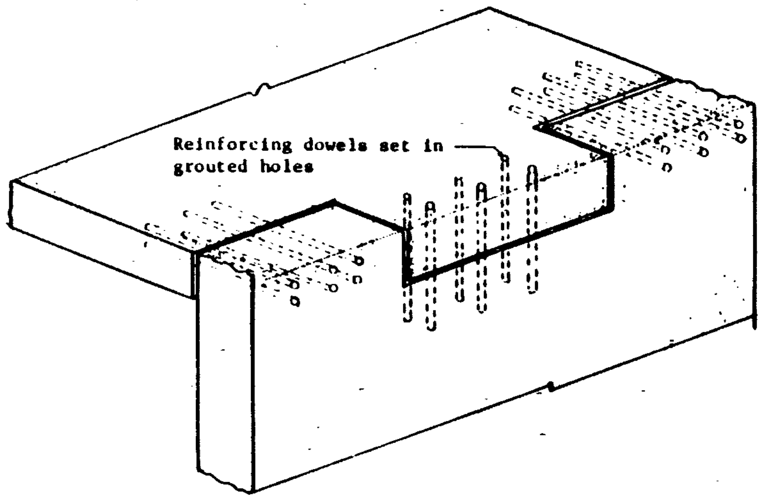


FIGURE D-5. PINNED LAP JOINT--PRECAST ELEMENTS.

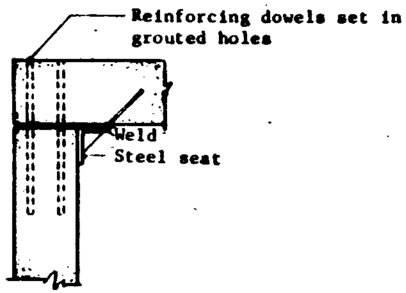


FIGURE D-7. SECTION G-G--PINNED LAP JOINT.

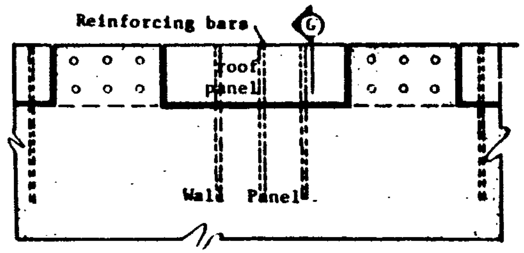


FIGURE D-6. ELEVATION--PINNED LAP JOINT.

guidance

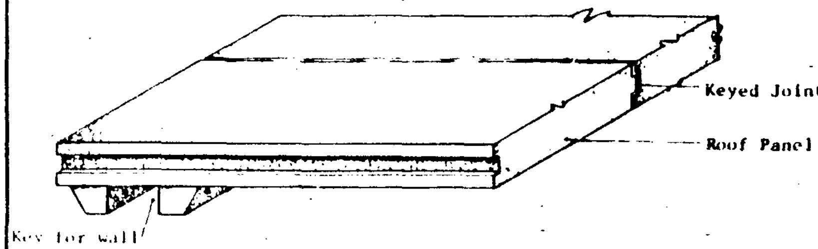


FIGURE D-8. KEYED JOINTS FOR PRECAST ELEMENTS.

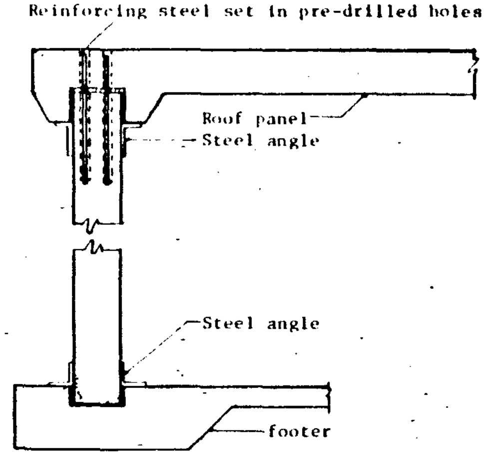


FIGURE D-9. WALL SECTION.

guidance

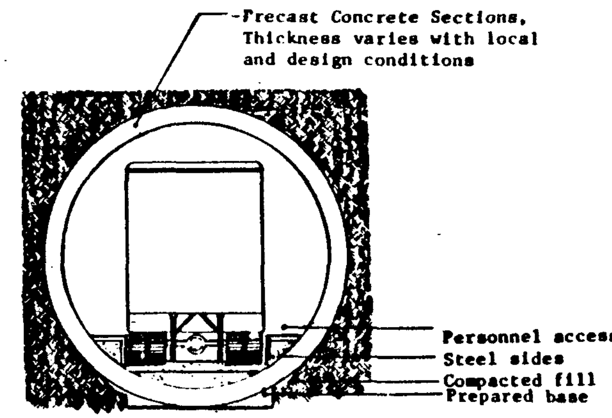


FIGURE D-10. PRECAST CONCRETE CIRCULAR SECTION.

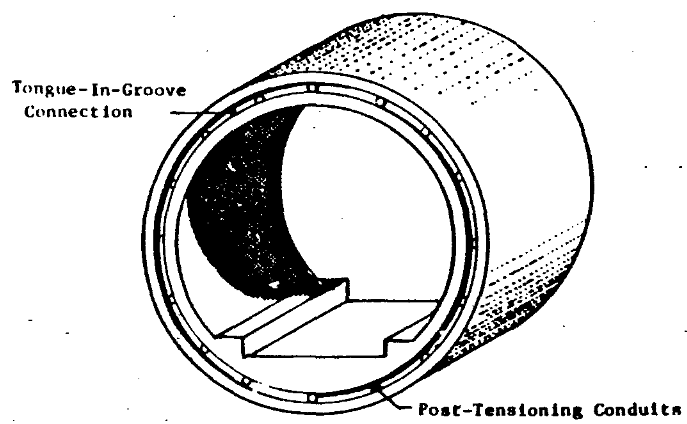


FIGURE D-11. CIRCULAR PRECAST CONCRETE SHELTER.

guidance

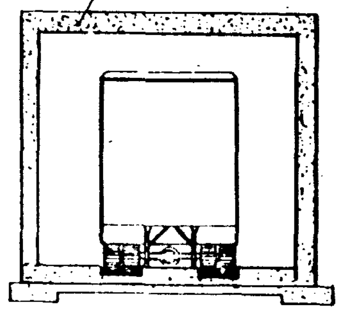


FIGURE D-12. PRECAST CONCRETE RECTANGULAR SECTION.

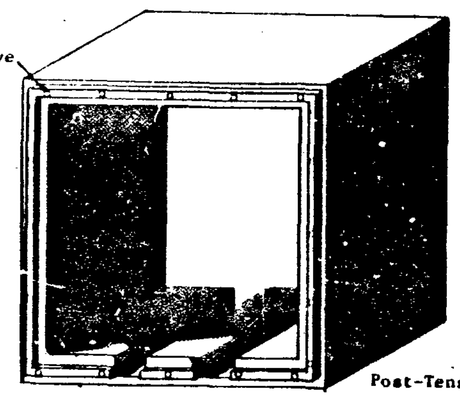


FIGURE D-13. RECTANGULAR PRECAST CONCRETE SHELTER.

guidance

guidance

03 Tilt-up panel construction

Structural wall panels could be cast adjacent to their final vertical position, then tilted up and anchored in place as the shelter is constructed. This variation of precasting has been used successfully in constructing commercial buildings and may be of some value to the semi-hardened shelters of interest. The wall panels could be cast horizontally on the foundation slab to minimize formwork and excavation, and the forming would be fairly simple. It is usually easier to construct horizontal panels rather than vertical panels, but much of these savings is lost when the work must be done 10 to 20 ft below grade. This technique also presents the same problems as other precast methods. For example, adequate strength can be developed across the joints for normal dead and live loads, but very little strength can be developed to resist lateral blast loads. The ductility factor has been set at unity--the lowest in the group--because of the inherent problems with the joints.

The joint problem in tilt-up construction can be eliminated partly by using the alternative construction illustrated in Figure D-14. Precast tilt-up panels are anchored securely to the floor slab through the use of turned-up reinforcing bars and a steel angle. A cast-in-place roof is used to securely anchor the reinforcing steel of the wall panels. The foundation slab is constructed with reinforcing steel turned upward to be incorporated into the joint at the base of the wall (Figure D-15). The foundation is formed to provide a keyway for the wall joint. A steel angle is then placed between the rows of reinforcing rods and welded to all exposed rods. Walls are cast with exposed reinforcing rods extending from both top and bottom of the panels (Figure D-16). These panels are cast on the foundation slab, lifted into place, and welded to the exposed foundation steel angle. After inspection, the cavity under the wall is pressure-grouted to form an integrated joint. The roof can be constructed in two different ways, both of which incorporate the reinforcing steel from the wall panels. In one method, conventional forms are placed, reinforcing steel is installed, wall steel is bent down into the roof steel mat, and concrete is placed to achieve the required slab depth. In the other method, the cost of forming is eliminated by using thin precast concrete slabs for forms and then placing the reinforcing rods and concrete on top. The thin slab also would eliminate the need for extensive shoring and forming, which should reduce overall construction time. Using either technique will ensure that fully integrated joints are formed and that the ductility factor is increased.

guidance

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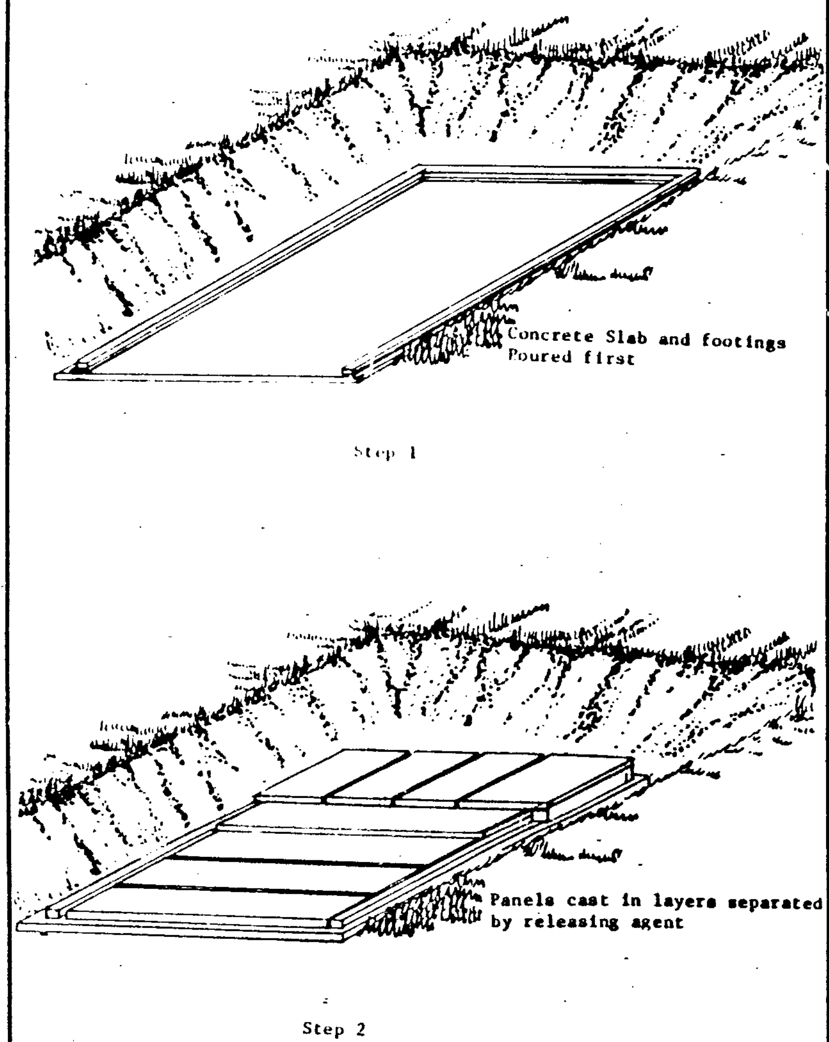


FIGURE D-14. TILT-UP PANEL CONSTRUCTION PROCESS.

guidance

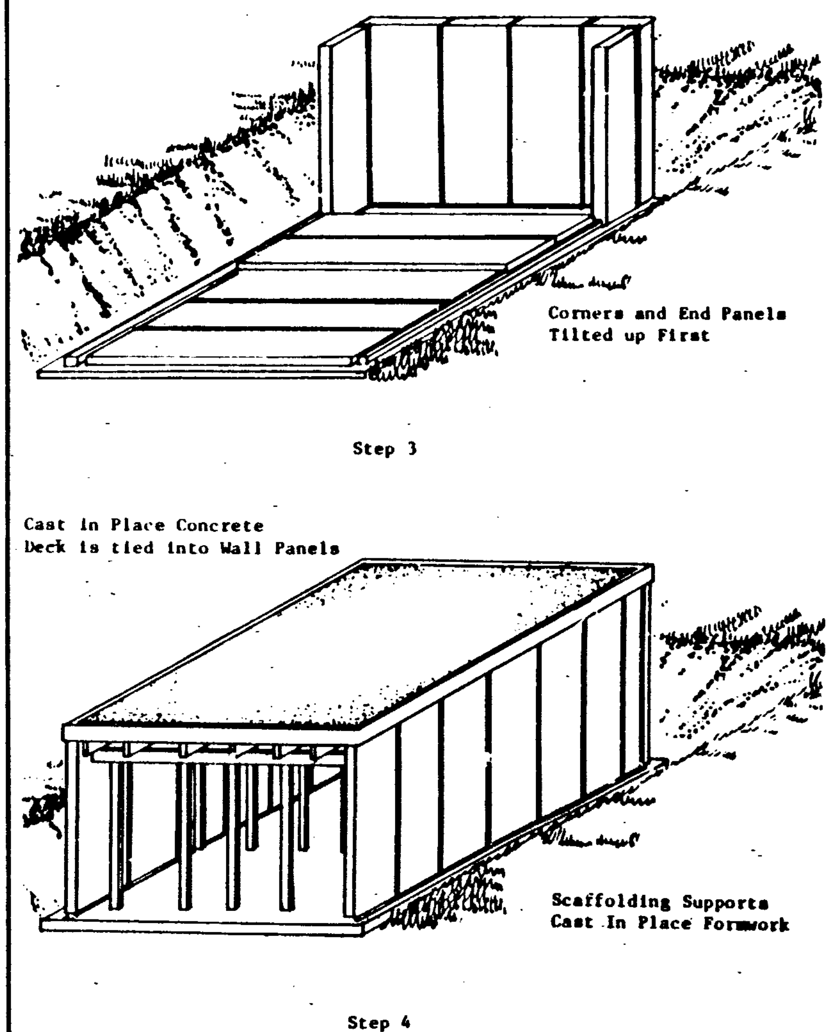


FIGURE D-14. TILT-UP PANEL CONSTRUCTION PROCESS (CONT'D).

guidance

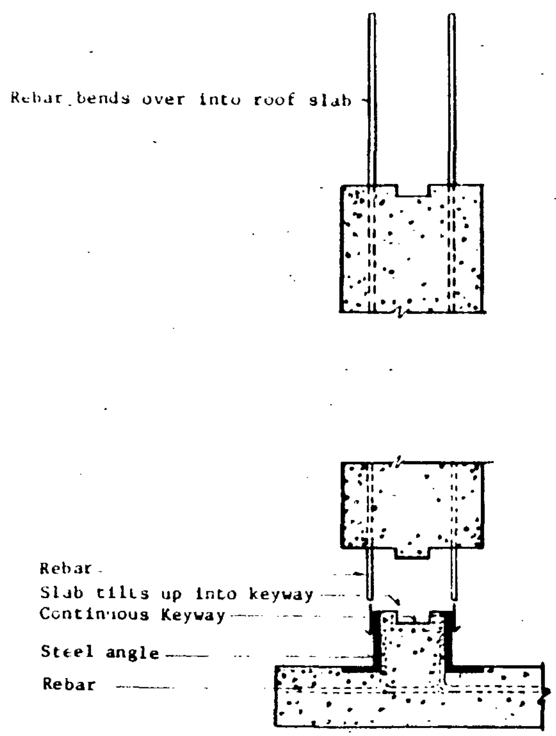


FIGURE D-15. PRECAST WALL PANEL--JOINTING TECHNIQUE.

guidance

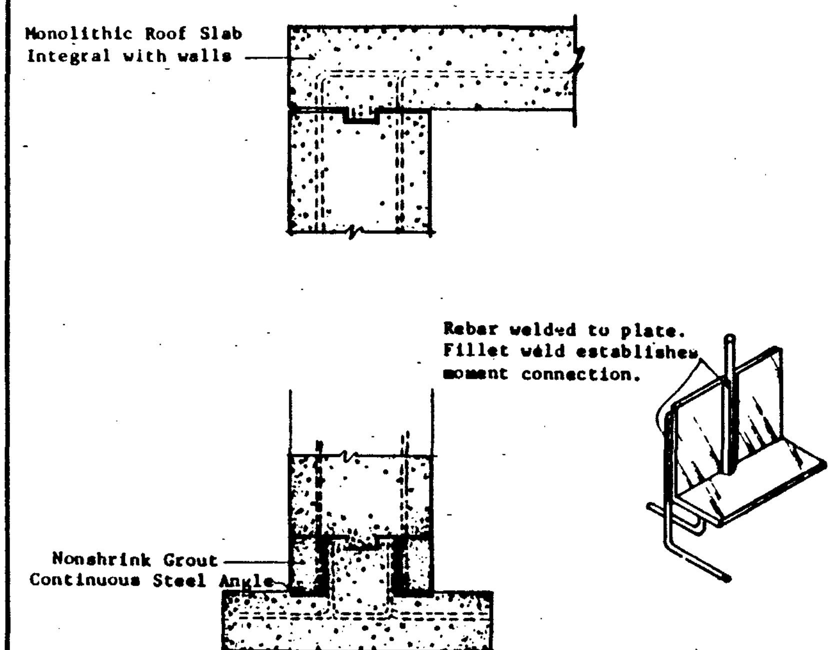


FIGURE D-16. WALL-TO-ROOF FOUNDATION JOINTS.

guidance

04 Double-panel wall construction

As an alternative to constructing thick walls to resist lateral loads, the shelter could be constructed with two thinner walls separated by a cavity filled with compacted soil. The compacted fill will transfer the load to the interior wall, allowing the walls to react as an integrated element. Walls could be cast-in-place or precast; however, the cast-in-place approach would produce the better product (Figure D-17). The cast-in-place technique has been selected for this analysis. The type of formwork used between the walls depends somewhat on the space available. Prefabricated wood or metal forms could be used if they are self-supporting and removable from the top of the wall. These special forms (Figure D-18) would have to be built in sections, heavily braced to take the lateral loads, and collapsible for removal with all controls near the top edge. Forms should be 3 ft high to allow the walls to be constructed in two lifts. After removing the forms, the cavity should be filled with compacted sand or selected soils. The finished lower section would serve as the foundation for the upper section. Or, disposable forms (Figure D-19) could be used and left in place, completely eliminating the need for special forms. Treated cardboard tabular forms appear to be a better alternative than the special collapsing type. The tabular forms can be placed in position, filled, capped and left in place, completely eliminating the need for inner forms on both walls. Concrete placed in the form will tend to fill the voids around the forms, making the composite wall more rigid. Special equipment may be required to compact the sand or soil in the forms.

guidance

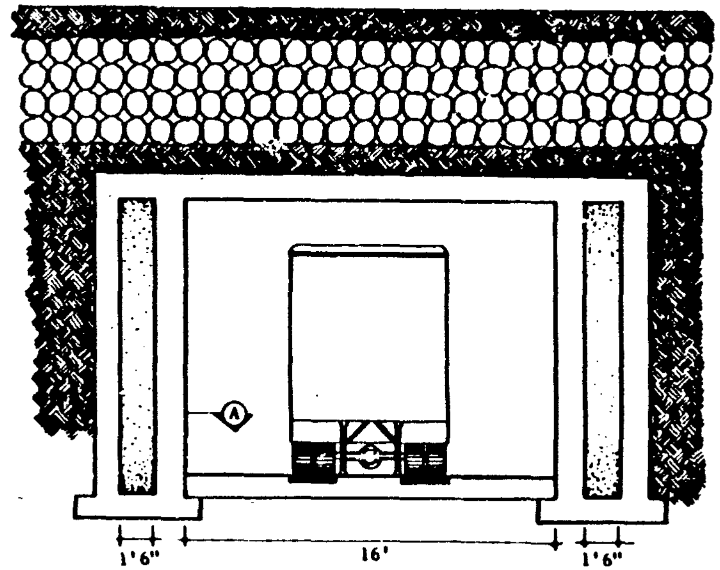


FIGURE D-17. TYPICAL SECTION--DOUBLE WALL CONSTRUCTION.

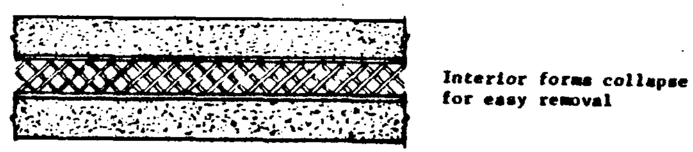


FIGURE D-18. DETAIL--COLLAPSIBLE FORM.

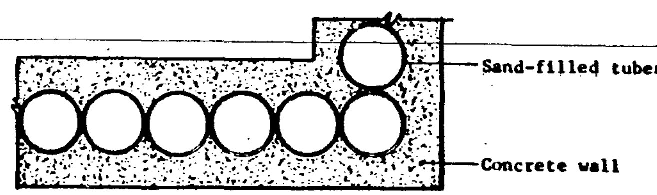


FIGURE D-19. DETAIL--DISPOSABLE FORM.

guidance

D5 Semicircular arch construction

The arch will be constructed of cast-in-place concrete and curved reinforcing steel bars placed over prefabricated forms. The exterior forming will be used in lifts to ensure placement and compaction of concrete at the lower edges. The arch inherently is able to resist heavier loads than the rectangular configuration shelters. However, the arch configuration requires more floor space to obtain the needed vertical clearances. By using a configuration similar to the baselined igloo (Figure D-20), the amount of floor space can be reduced and made more usable, but it still exceeds that required with the rectangular configuration. Figures D-21 through D-24 illustrate different arch configurations.

As an alternative, a semicircular shelter could be constructed using an inflated form, insulating foam, and sprayed-on fibrous concrete following the steps shown in Figure D-25. A conventional foundation slab is constructed with reinforcing steel stubbed up to be incorporated into the roof. An air-inflatable form is then placed on the slab and inflated to provide the form for the roof. The form is covered with sprayed-on foam to a 6-in. expanded thickness to provide insulation and to protect the form from steel wires in the fibrous concrete. After the foam cures, the form is deflated and removed. Fibrous reinforced concrete is shot onto the foam surfaces to the required thickness, incorporating the foundation reinforcing rods into the resulting structural cover. The end walls and entrance wing walls can be constructed easily using conventional techniques.

guidance

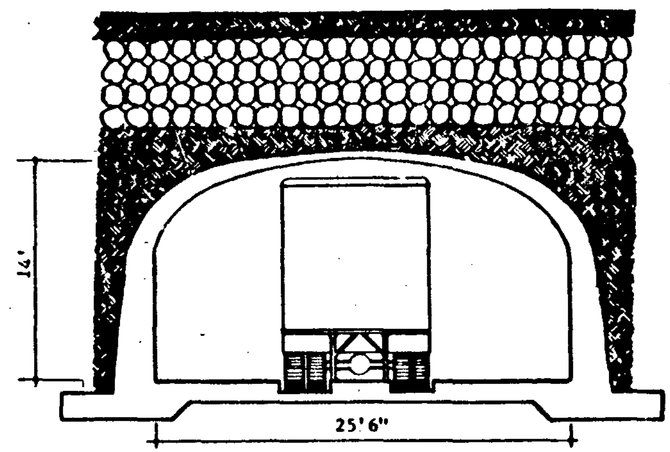
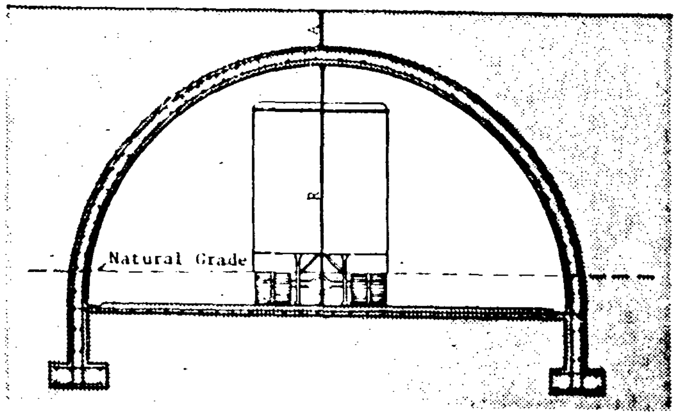


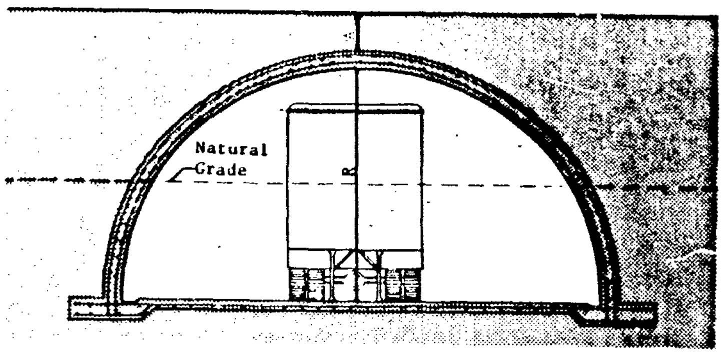
FIGURE D-20. IGLOO CONSTRUCTION.

guidance



ALTERNATIVE A

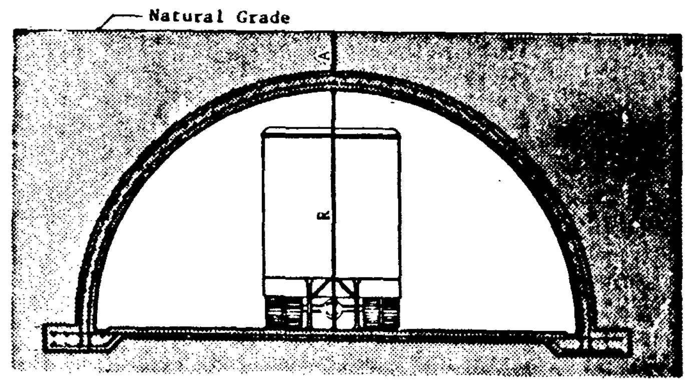
FIGURE D-21. SEMICIRCULAR ARCH--ALTERNATIVE A.



ALTERNATIVE B

FIGURE D-22. SEMICIRCULAR ARCH--ALTERNATIVE B.

guidance



ALTERNATIVE C

FIGURE D-23. SEMICIRCULAR ARCH--ALTERNATIVE C.

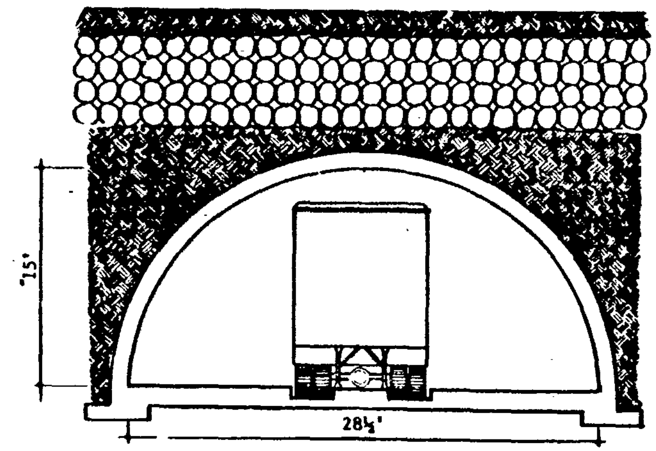
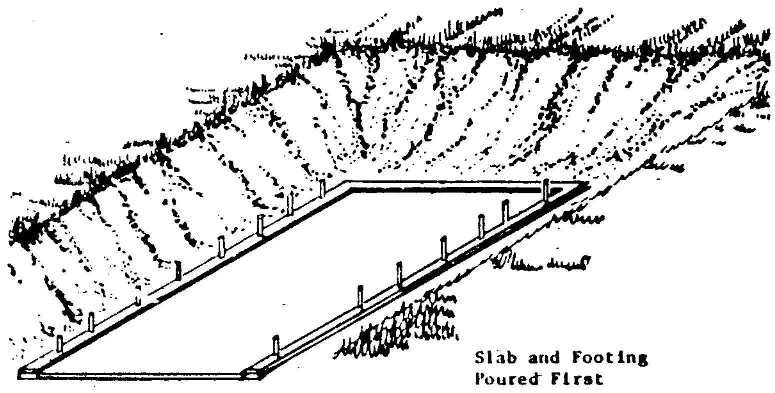
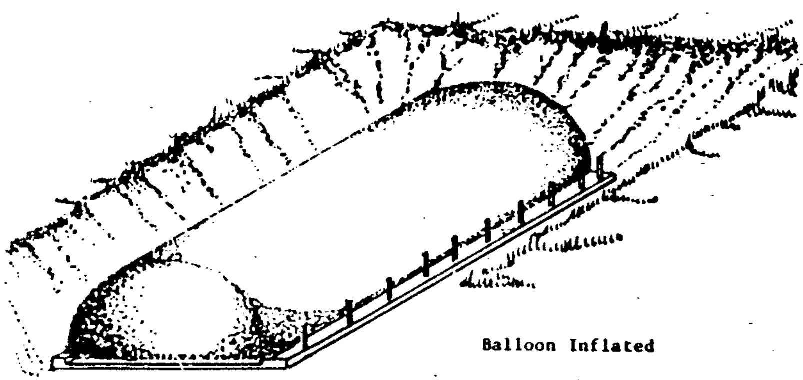


FIGURE D-24. SEMICIRCULAR ARCH CONFIGURATION.

guidance



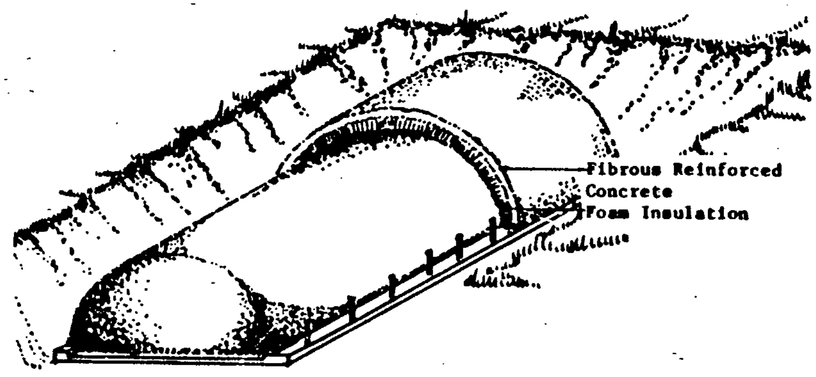
Step 1



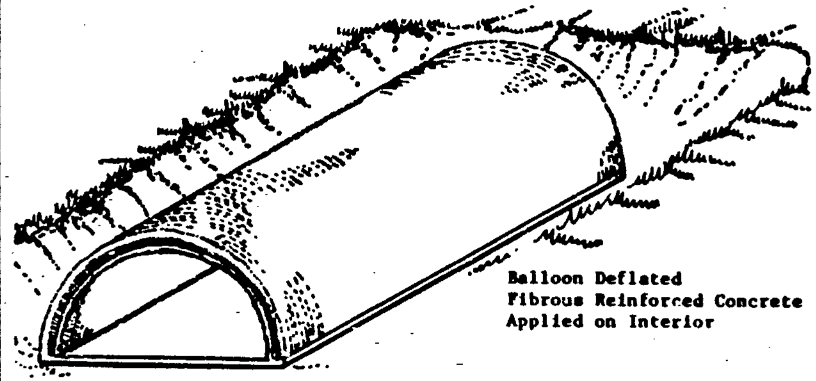
Step 2

FIGURE D-25. INFLATABLE FORM, FOAM, AND SHOTCRETE CONSTRUCTION.

guidance



Step 3



Step 4

FIGURE D-25. INFLATABLE FORM, FOAM, AND SHOTCRETE CONSTRUCTION (CONT'D).

guidance

D6 Circular construction

Large-diameter pipes and tunnel liners could be used to shelter the equipment by using fill in the bottom quadrant to form adequate interior floor space (Figures D-25 and D-27). Because of the needed diameters, the circular structures would have to be precast in sections or cast-in-place. Constructing such a shelter in place may eliminate economic advantages because of the intensive use of special forms.

As an alternative to conventional construction, the shelter could be constructed of integral longitudinal segmented sections precast on-site and interconnected with posttensioning tendons as discussed in paragraph D2.

The basic structure could be constructed of corrugated metal sections with bolted field connections and covered by fibrous concrete (Figures D-26 and D-27). Shear pins or other devices for increasing the bond between the metal and concrete would have to be installed before applying the fibrous concrete. The completed structure's strength would depend on the strength of the horizontal bolted joints. These joints would need to be staggered so that joints in adjacent panels are at least 24 in. apart.

The corrugated metal/fibrous concrete structure could be coated with 4 to 6 in. of polyurethane foam after shotcreting. This composite structure should be more resistant to blast loading since the foam layer would absorb part of the blast and reduce the deflection of the fibrous concrete, thus lowering resultant stresses on the bolted connections.

guidance

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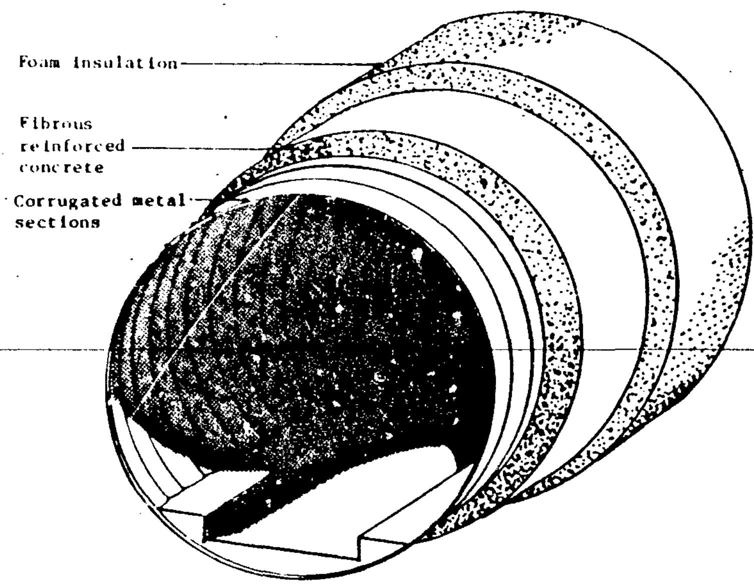


FIGURE D-26. CORRUGATED METAL, FOAM, AND FIBROUS CONCRETE CONSTRUCTION.

guidance

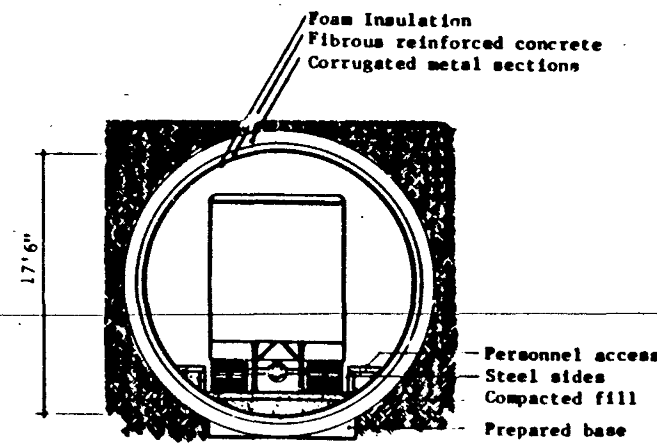


FIGURE D-27. SECTION.

guidance

D7 Concrete/prefabricated box forms

The time required to construct the shelters by conventional techniques can be reduced by using prefabricated box forms and reinforcing steel cages placed on a prepared foundation slab. The forms would remain in place to comprise the inner liner of the shelter. The box forms would be limited to 8 ft wide to make them truck-transportable. The basic box could have a cross sectional dimension of 8 by 8 ft by 20 or 40 ft long (same dimensions as the standard MILVANs) or a higher roof height if 8 ft is restrictive. Boxes would be complete with a structural floor, wood-lined walls, and wall channels for mounting equipment. Much of the equipment could be installed in the box forms before shipment as a way to reduce both shipping volume and installation time in the field. The forms' spacing on the foundation slab will determine the thickness of the interior load-bearing walls. Conventional forming is limited to the exterior surfaces. The few different form types required to build this type of structure would include the standard box, those to build walkways between the boxes, and those for constructing the hardened entrance. Two blast doors, separated by the generator shelter, would satisfy the safety criteria. Emergency control would be based on a central chiller and small AHUs in each space. Ceiling-hung ducts would distribute the outside air.

The building configuration (Figures D-28 through D-31) in this analysis is flexible and can be changed easily to better suit local operational or geographical conditions.

guidance

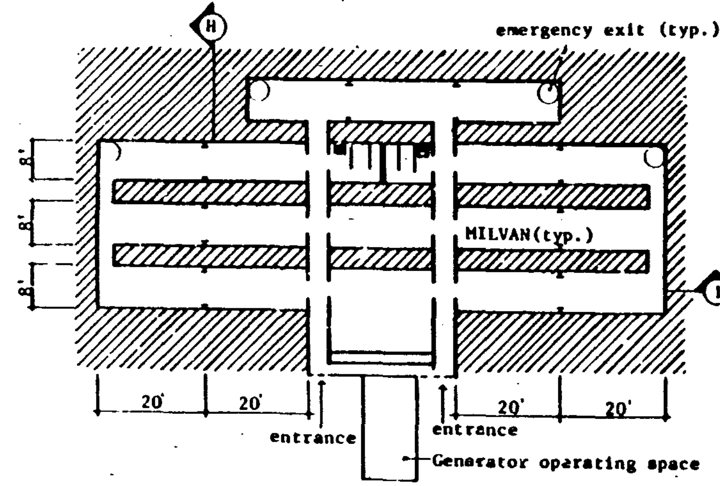


FIGURE D-28. PREFABRICATED BOX FORMS--FLOOR PLAN.

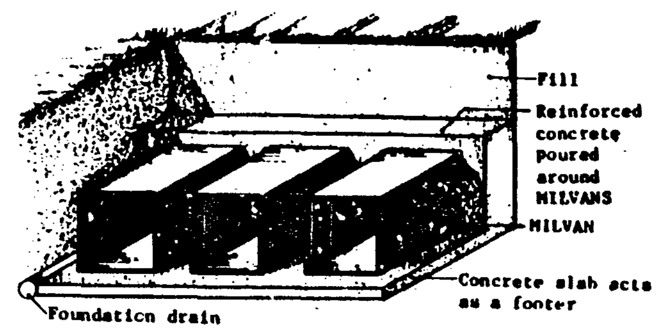


FIGURE D-29. CONSTRUCTION TECHNIQUE--PREFABRICATED BOX FORMS.

guidance

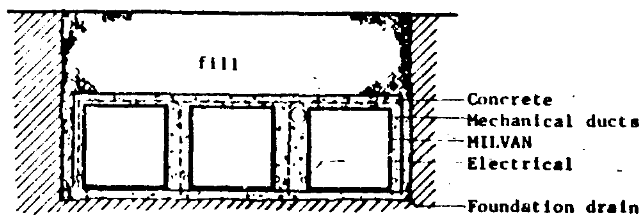


FIGURE D-30. SECTION H-H.

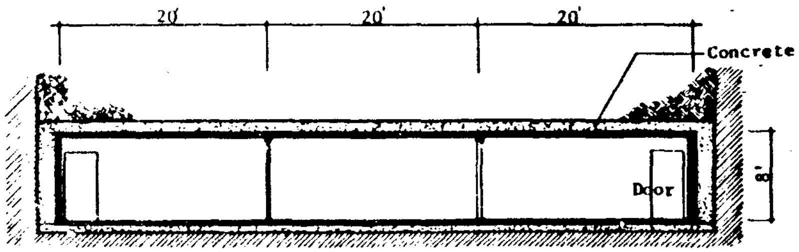


FIGURE D-31. SECTION I-I.

guidance

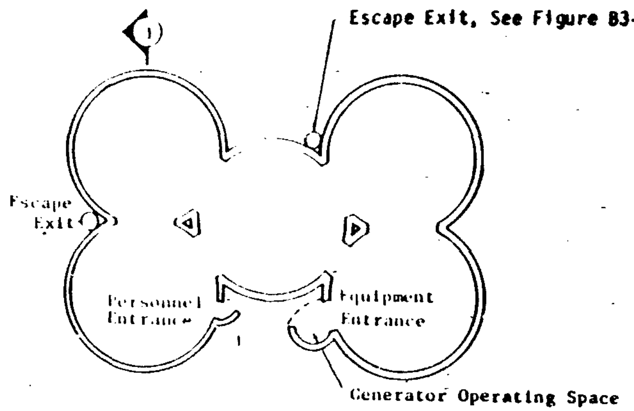
08 Dome construction

Structural domes can provide needed operational space rapidly. Domes have been used successfully for years to satisfy a wide range of shelter requirements. Recent experience has been gained with fibrous reinforced concrete over polyurethane foam which has been sprayed onto an inflatable form. The U.S. Army Construction Engineering Research Laboratory (USA-CERL) has constructed domes up to 50 ft in diameter, and others exceeding 150 ft in diameter have been built. A dome 28 ft in diameter was selected for this analysis to keep the excavation depth approximately the same as for the rectangular section shelter built to provide operational space. The dome should be constructed on a prepared foundation. A rubber balloon form would be placed on the foundation, inflated, and covered with approximately 6 in. of polyurethane foam. After curing, the foam would be cut to form doorways and other openings and to remove the deflated balloon.

Openings can be made in foam structures in at least two ways. The foam is easily cut to form doorways, and the joints between foam surfaces and wood or metal surfaces filled with additional foam. Door frames can also be placed on the form and included in the initial spraying, since foam bonds very well with other surfaces. Two in. of fibrous concrete would be sprayed on the dome's interior and the rest of the needed concrete thickness would be sprayed on the exterior. Concrete would be applied in approximately 1-in. layers. When the concrete cures, the backfill and protective rock layers can be placed.

The resulting structure (Figures D-32 and D-33) is a heavily insulated, reinforced concrete facility complete with interior fire-proofing. The dome is hemispherical, providing a 14-ft ceiling height in the center for mechanical equipment, storage platforms, or other purposes. AHUs should be placed in the center of each dome either on the floor, on a pedestal, or on a platform to reduce the use of floor space. Chilled water lines should be placed under the floor. Partial hemispherical dome structures should be used to protect the personnel entrance and generator operating area. Interior areas could be subdivided easily using partitions to meet operational requirements.

guidance



28 ft. diameter Domes

2" fiberous concrete on inside
4" or more on the outside

AHU in center of each space

FIGURE D-32. DOME CONSTRUCTION--FLOOR PLAN.

guidance

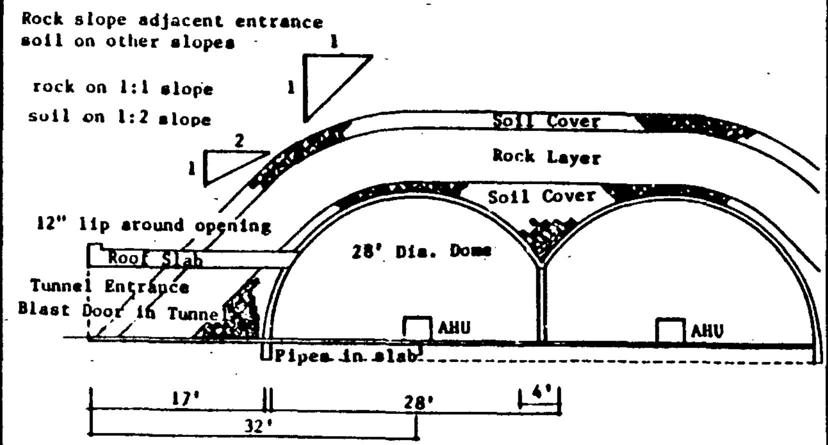


FIGURE D-33. SECTION J-J.

SECTION E ANALYSIS & CONCLUSIONS

guidance

STRUCTURAL DESIGN

Structural concepts

Within the constraints of threat definition, the hardening required for the shelters dictates that a rock rubble/boulder blanket or, alternatively, a concrete burster slab be incorporated into the protective cover to defeat the effects of direct hits from artillery rounds. Therefore, this analysis focused on a series of below-ground concepts using rectangular, semicircular, and dome configurations and various construction techniques and materials described in Section D.

Point of detonation

The important variables affecting threat loading intensity on the shelter are: (1) weapon size and the distance from the point of detonation to the structure, (2) mechanical properties of the soil and rock, and (3) the projectile's depth of penetration. The rock rubble blanket will reduce the resulting blast load on the roof from direct hits by artillery rounds. If the projectile detonates too near the shelter, however, the shelter will fail due to localized breaching. The rock rubble blanket's function is to either destroy the incoming projectile at impact or reduce its penetration depth and increase the explosion standoff distance. The penetration depth into a dense medium such as the rock blanket depends on the following variables:

1. Characteristics of the projectile such as weight, caliber or diameter, length, nose shape, and structural integrity (rigidity, wall thickness, etc.)
2. Striking conditions such as impact velocity, angle of incidence, and yaw.
3. Properties of the rock rubble blanket such as the rock hardness, caliber, number of layers of and shape of boulders, and the placement method.

In general, depending on the interaction of all these variables, any of the following situations could prevail to defeat the projectile or reduce its effectiveness:

1. The projectile could break upon impact.
2. The projectile could ricochet or broach after impacting the rock rubble blanket.
3. The projectile's path could be deflected.
4. The projectile's path could be deflected and it could detonate at some location within the rubble blanket.

For the analysis in this study, it was assumed that the projectile would enter the rock blanket and detonate at approximately the midpoint of the rock rubble blanket along the centerline of the roof.

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For the case of a near miss by a bomb, the detonation point was assumed to be located along the shelter wall centerline. The nearest assumed point of detonation was set at 40 ft, which exceeds the edge of the rock rubble blanket. The rock rubble blanket would provide little protection against bomb attacks for partially and totally buried shelters; however, the rock could be extended to provide this protection if desired. Completely mounded shelters do benefit from the rock rubble blanket since rock nearly covers the shelter's complete vertical profile and would produce ground-burst from the bombs.

Thickness limitations

The following practical limitations on thickness were established for the various types of construction considered in this analysis. The actual thickness for precast and tilt-up concrete elements actually depends on the size or weight of the structural element and the availability of suitable lifting equipment.

Construction	Thickness (in.)
Cast-in-Place Concrete	60
Fibrous Reinforced Concrete	60
Precast Concrete	36
Shotcrete	36
Tilt-up Concrete	24

Design method

It is possible to design the shelter on an elastic basis using normal code limits, to withstand the large dynamic loads described in the threat; however, severity of these loads would make the design very costly. Designs that use localized plastic deformation to absorb the energy imparted by these loads are desirable; in fact, they are generally mandatory for maintaining practical structural proportions, provided the overall integrity on the structure is not impaired. Accordingly, the design and proportioning of the structural elements were based on ultimate strength design methods, the material's dynamic properties, and the structural elements' dynamic response.

A simplified, rapid procedure was used in designing the shelters to resist the dynamic loads produced by the primary threat. This method of analysis required: a description of the loading time curve on the structures and knowledge of the limiting structural resistance; the

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shape of the resistance-deflection curve for the structure, and especially a characterization of it by a ductility parameter that gives the permissible maximum deflection in relation to the structure's effective yield point deflection; and a measure of the period of vibration in the structure's effective "elastic range." This procedure is accurate enough to analyze the resistance because the parameters entering the problem cannot be determined accurately. This is due to a lack of definitive knowledge concerning: (1) the blast pressure at a given distance from a given energy detonation; (2) the blast wave duration; and (3) the structural parameters. The details of this procedure are described elsewhere.[1]

Structural deformations often are described in terms of ductility ratio, which is the ratio of the maximum deformation to maximum elastic deformation. Members that have large ductility ratios can absorb more strain energy and are thus more efficient in resisting dynamic loads. Furthermore, for buried structures, ductility is essential in order to permit the structural deformations required to take full advantage of the inherent strength of the soil surrounding the structure. Soil resistance can be mobilized only after deformations are imposed upon it.

The ductility factor that corresponds to collapse for various structures ranges from slightly greater than 1 for brittle structures to more than 20 for very ductile structures. The ductility factor used in these particular designs was assumed to be controlled by the material's ductility limit at failure rather than by functional requirements. Since the shelters are required to withstand multiple loadings, the normal ductility factors for single loading were reduced by a factor of approximately 2 to provide reasonable assurance that enough reserve energy absorption capacity would be available for multiple loadings. The ductility ratios used in the preliminary design are:

Construction Type	Ductility Factor Failure Mode	
	Ductile	Brittle
Cast-in-Place	5.0	1.0
Precast Concrete Segmental Units	3.0	1.0
Conventional Elements	1.5	1.0
Tilt-Up Elements	1.0	1.0
Shotcrete	2.0	1.0
Fibrous Concrete	2.0	1.0

[1] N. M. Newmark and J. D. Haltiwanger, Principles and Practices for Design of Hardened Structures, Air Force Manual AFSWC-TDR-62-168 (Air Force Special Weapons Center, Kirkland AFB).

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CONSTRUCTION COST ESTIMATES

Assumptions

Construction cost estimates for the various shelter concepts were based on the following assumptions:

1. The proposed construction sites are located on or near existing installations. Real estate costs have not been included.

2. The proposed construction sites are located near populated areas; therefore, costs for mobilization and crew life support have not been included.

3. There are no unusual construction conditions at the proposed sites.

4. Utilities are available at the proposed construction sites.

5. There are no local, regional, or national shortages of materials that would affect construction.

6. Costs for roads, storm drainage, electrical service and communication lines, and other site development work beyond the 5-ft line of the facility have not been included.

7. No cost for possible impact on existing support has been included.

8. The daily construction output is based on an 8-hr day in daylight with no allowance for overtime.

9. The site and construction technique will have no impact on the existing transportation system.

10. Construction costs will not be affected by weather, season, contractor management efficiency, local union restrictions, local construction requirements or availability of adequate energy, manpower, and materials.

Unit costs

Unit cost data were obtained from the following sources:

1. Army Regulation (AR) 415-7, Construction Cost Estimating for Military Programming, (U.S. Department of the Army, 1980).

2. Annual Construction Pricing Guide (U.S. Air Force, 1983).

guidance

3. Robert Snow Means Co., Means' Building Construction Cost Data (Kingston, MA, 1983).

4. Robert Snow Means Co., Means' Mechanical and Electrical Cost Data, 6th ed. (Kingston, MA, 1983).

5. Robert Snow Means Co., Means' Building System Cost Guide, 8th ed. (Kingston, MA, 1983).

6. W. J. Wooley Company, Oak Brook, Illinois, cost data on blast-resistant doors.

Specific in-place cost data were developed for the shelters' conceptual construction cost estimates. Mechanical, electrical, and blast door costs were developed on a lump-sum basis because they were generally constant for a given concept and insensitive to whether the shelters would be constructed above or below grade.

Cost estimate adjustment factors

The unit cost data were used to develop an unadjusted expected facility cost based on an assumed construction date of January 1984 and a geographical location reflecting Washington, D.C. These estimates must be adjusted by various factors to reflect actual costs in specific geographical areas, the cost growth expected due to economic factors that apply to construction projects scheduled differently from the stated assumptions, a reserve for construction contingencies to cover unexpected conditions, and supervision and administration. The values assigned to the adjustment factors were:

1. Location	1.00
2. Cost growth	1.00
3. Contingencies	1.05
4. Supervision and administration	1.05

For geographical areas other than Washington, D.C., and a midpoint date other than January 1984, Tables E-1 and E-2 can be used to determine the proper location and cost growth factors needed to adjust the estimated cost.

When evaluating the concepts for economic feasibility, note that it is not the actual construction cost which is most important, but the relative cost among alternative concepts and how they compare to baseline costs.

guidance

Costing issues

1. Above- Versus Below-Ground Construction. To determine if a significant cost advantage is associated with locating the shelters below as opposed to above ground, a shelter for the transportable unit was designed and costed in both configurations with similar construction methods and siting conditions assumed. The results of this analysis indicated that, for all practical purposes, the costs for these configurations were identical, with any differences attributed to the design procedure accuracy. Therefore, for this investigation, the cost reported can be assumed to apply to all three configurations.

The partially mounded approach appears to be the fastest, least expensive way to construct and probably suited best for a wide range of locations.

Above-ground construction greatly simplifies site preparation and construction techniques, improves site accessibility, and reduces the cost of the entrance ramp and related pavements. The approach does require an excessive amount of soil for the mound. In addition, the soil must be furrowed and hauled to the site and the rock rubble blanket must be extended to cover the entire building configuration. The mound width could easily range from 120 to 150 ft.

Totally buried construction eliminates the need for constructing a large mound. The waste from the excavation can be used to backfill around the structure and reslope the surface for natural drainage. The entrance ramp, sloped at 30 degrees, would require a 50-ft extension to return to grade. However, this ramp, being a long open pit, could easily collect debris during an attack and this would have to be removed before the truck can be moved and the stored equipment used. In addition, cranes used for lifting heavy precast sections would have to be located more than 30 ft from the centerline of the building, which may limit the precast elements' size. Constructing the facility in a 30-ft-deep pit also would increase the cost of material handling and require additional equipment.

Partially buried construction would permit a better balance between the earthwork cut and fill, often eliminating the need to transport fill material to the site. Construction would start about 8 ft below grade, which is not an unusual depth, and conventional techniques can be used. The entrance ramp would be very short compared with that required for the totally buried building. In addition, totally buried shelters may be impractical to construct in the field due to the local terrain and the presence of a high groundwater table, saturated soil, and/or rock.

2. Cast-in-Place Concrete Unit Prices. To determine the sensitivity of the total facility cost to the in-place unit cost of cast-in-place concrete, excluding steel reinforcement, the cost of the concrete in the transportable unit shelter was varied by plus- and minus-50 percent of the estimated value. The resulting change in the total facility cost was approximately 10 percent in each case.

3. Width of the rock rubble blanket. The rock rubble blanket was extended to a distance approximately 20 ft beyond the shelter's vertical projection to provide reasonable assurance that the shelter would not be damaged by a direct hit. However, it may be desirable to extend the

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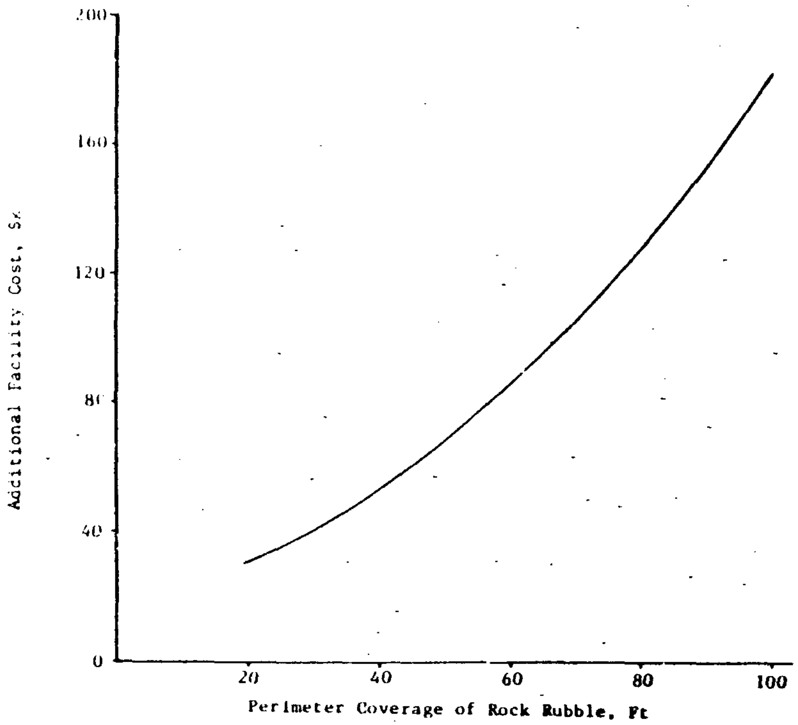

FIGURE E-1. ADDITIONAL FACILITY COST FOR EXTENSION OF ROCK RUBBLE BLANKET.

guidance

rock rubble blanket to a greater distance to improve the shelter's resistance to near misses by bombs. Figure E-1 illustrates the additional cost for extending the rock rubble blanket beyond the normal limits for a shelter housing the transportable unit. For example, an additional 20 ft of rock rubble perimeter coverage would cost another $20,000.

FINDINGS

The optimal thickness of the protective soil and rock rubble layer was determined by a series of analyses that considered both a typical rectangular and semicircular shelter cross sections. In Figure E-2, the burial depth is related to the roof thickness and weight of explosives. The roof thickness can be minimized at an 8-ft burial depth because a slight increase in thickness results in a major increase in explosive weight. The protective cover was assumed to contain a rock rubble blanket that would cause the round to detonate at the cover's midpoint. Below 8 ft, the protective layer's weight rather than the explosive weight, would determine the roof thickness. Figure E-3 addresses arch thickness requirements as a function of burial depth for the specified threat. Here again, it appears that an 8-ft burial depth is optimal. This depth therefore was selected as a constant for all structures in this analysis.

In general, member proportions were determined by the blast conditions from a near miss by the specified bomb; however, when the range exceeded 100 ft, the roof thickness was determined by the artillery round impacting on the center of the roof. Range, the perpendicular distance from the structural wall's midpoint to the point of bomb detonation, was varied between 40 and 100 ft in the analysis. At ranges less than 40 ft, member proportions approached or exceeded the practical limits for cast-in-place reinforced concrete. At this point, the failure mode for the shelter would begin to change from ductile to brittle. In addition, cratering effects and the damage that can be caused by ejecta would begin to be a concern. For ranges exceeding 100 ft, there appears to be only a minor change in member proportions as the range increases.

a. Rectangular section. Figure E-4 shows the typical wall designs required to withstand the specified blast conditions. Wall thickness for cast-in-place concrete construction varies from 9 to 37-1/2 in. over the bomb range of interest. Wall thicknesses for the other construction alternatives exceed their practical thickness limitations when the range is less than 50 ft for precast and shotcrete and less than 70 ft for tilt-up construction. The curves appear as dashed lines when the practical thickness limits are exceeded.

b. Double-panel wall section. Composite double-panel wall sections, i.e., elements composed of two concrete panels separated by a sand-filled cavity, have certain characteristics useful to semihardened design for structures located close to a detonation point. However, when the wall thickness was determined for the specified threat, the panel's thickness was governed by the min-

guidance

imum wall thickness requirement rather than structural loading for ranges exceeding 50 ft (Figure E-5). The design was found to be noncompetitive at ranges exceeding 60 ft when compared to cast-in-place concrete. Although it might be competitive at ranges less than 40 ft, this is the region in which cratering and ejecta would dominate.

c. Semicircular arch section. Compared to the rectangular configuration, the semicircular arch section requires more floor space or building volume to provide the needed vertical clearance. Since the rectangular and circular sections use the building volume much more effectively than the semicircular section, the semicircular section was dropped from the list of feasible alternatives.

d. Circular section. Figure E-6 shows the typical wall designs required to withstand the specified threat. In general, the wall thickness for the circular section is less than that required for the rectangular section. In the case of cast-in-place concrete, the wall thickness for the circular section is about 25 to 40 percent less than that for the rectangular section. Similar reductions in wall thickness can be observed for the other construction alternatives. This reduction is attributable to the way in which a circular section resists the imposed loads, i.e., a combination of thrust and bending rather than pure bending.

e. Composite circular section. This consists of a bolted corrugated multiplate circular section covered with fibrous concrete and a cellular foam. The foam would absorb energy from a shock wave and transfer stress uniformly to the composite wall section. It has been assumed that the foam would reduce the blast loading on the composite wall section by about 50 percent. Figure E-7 shows typical thicknesses for fibrous concrete in the composite wall section; these vary from 4 to 15 in.

f. Concrete prefabricated box section. Wall and roof designs for the concrete prefabricated box section were developed using procedures similar to those used for the rectangular section, but with reduced span lengths. Figure E-8 illustrates the wall designs. As expected, the wall and roof thicknesses were substantially less than those for the larger rectangular section. Both thicknesses varied from 6 to 22 in. over the threat range of 40 to 100 ft; however, the curves followed slightly different paths between these two points.

g. Dome section. The wall thickness for the fibrous concrete dome section was determined by the imposed loading and the sections' compressional load-carrying capacity. In addition, it was assumed that the minimum section thickness was 2 in. Figure E-9 illustrates the dome thickness as a function of the blast range. In the 40- to 60-ft range, the curve is approximately linear; thereafter, it approaches the minimum thickness dimension.

guidance

Transportable unit

Construction costs were estimated developed for below-ground shelters for the transportable units using different configurations and conventional cast-in-place concrete construction as well as various construction alternatives described in Section D. Each shelter was designed to withstand the specified threat.

a. Rectangular configuration. Figure E-10 shows construction cost estimates for the transportable unit rectangular shelters for cast-in-place reinforced concrete as well as the shotcrete and precast construction alternatives. Dashed lines appear where the member proportions exceeded the practical wall thickness limits established previously. For conventional cast-in-place concrete, the total facility costs varied from about $540K to $885K, depending on the range. Corresponding unit costs varied from $267 to $438/sq ft. The shotcrete, tilt-up, and conventional precast alternatives have limited ranges of application and, in general, are more expensive than cast-in-place concrete. Although the double-wall panel and segmental precast constructional alternatives can be used over the range of interest, both alternatives appear to be slightly more expensive than the cast-in-place shelter. Local construction experience and site peculiarities may govern the selection of the most economical construction method.

b. Circular configuration. Figure E-11 gives construction cost estimates for the transportable unit circular shelters for cast-in-place reinforced concrete as well as the shotcrete and precast construction alternatives. Dashed lines appear where member proportions exceeded the practical wall thickness limits established previously. For the circular cast-in-place reinforced concrete shelters, the total facility costs varied from about $600K to $1000K, depending on the range Corresponding unit costs varied from $300 to $500/sq ft, respectively. The composite wall section using foam, fibrous concrete, and corrugated multiplate section and the precast segmental units both were over about 15 percent higher. In general, the other construction alternatives are more expensive than conventional cast-in-place concrete.

Reconstitutional package

Construction costs were estimated for below-ground shelters for the reconstitutional package using procedures similar to those used for the the transportable unit. For the rectangular cast-in-place reinforced concrete section, the total facility cost varied from about $400K to $575K as the range decreased from 100 to 40 ft (Figure E-12). The corresponding unit cost varied from about $540 to $777/sq ft, respectively. For the circular cast-in-place reinforced concrete section, the total facility cost varied from about $430K to $630K (Figure E-13). The

guidance

corresponding unit cost varied from $580 to $850/sq ft. These costs are about twice the unit costs for the transportable unit and suggest that hardening the shelters for reconstitutional packages may not be cost-effective for the deployment concept under consideration. Perhaps several reconstitutional packages could be consolidated into a single larger shelter similar in size to the transportable unit shelter to reduce the total facility cost. In general, the other construction alternatives have the same limitation as discussed in the section on transportable unit shelters.

Operational shelters

Construction cost estimates were developed for the operational shelter as (1) a facility integrated with the transportable unit shelter and (2) a stand-alone facility. The integrated facility would be more cost-effective due to savings in concrete and steel when common walls and earthwork are used. First, however, this concept must be established as operationally feasible.

a. Integrated operational and transportable unit shelters. Figure E-14 shows construction cost estimates for the facility with a rectangular section. For cast-in-place reinforced concrete construction, the cost varied from $895K to $1415K. Corresponding unit costs varied from about $166 to $262/sq ft. The combined cost for individual stand-alone facilities varied from 36 to 60 percent more over the same range compared to the integrated facility. The curves' shapes in Figure E-14 are similar to those for the transportable unit with a rectangular section; total cost decreases rapidly as the range increases from 40 to 80 ft.

b. Stand-alone operational shelter. Figure E-15 shows construction cost estimates for a stand-alone rectangular cast-in-place operational shelter with the layout shown in Figure B3-12. The total facility costs varied from $690K to $1010K and the corresponding unit costs varied from about $190 to $280/sq ft.

c. Concrete/prefabricated box section. Construction costs were estimated only for the cast-in-place reinforced concrete construction concept (see Figure E-15). The total facility costs varied from about $685K to $930K. Corresponding unit costs ranged from about $205 to $280/sq ft. Because of the shorter roof and wall spans, the total facility costs were less sensitive to range than the other types. The total facility costs were developed assuming new shipping containers would be used. A substantial cost savings, about $175K to $200K, would be realized if used containers were substituted.

d. Dome section. Figure E-15 shows construction cost estimates for the operational shelter using the dome construction alternative. The total facility costs varied from $560K to $670K over the range. Corresponding unit costs varied from $180 to $220/sq ft, respectively.

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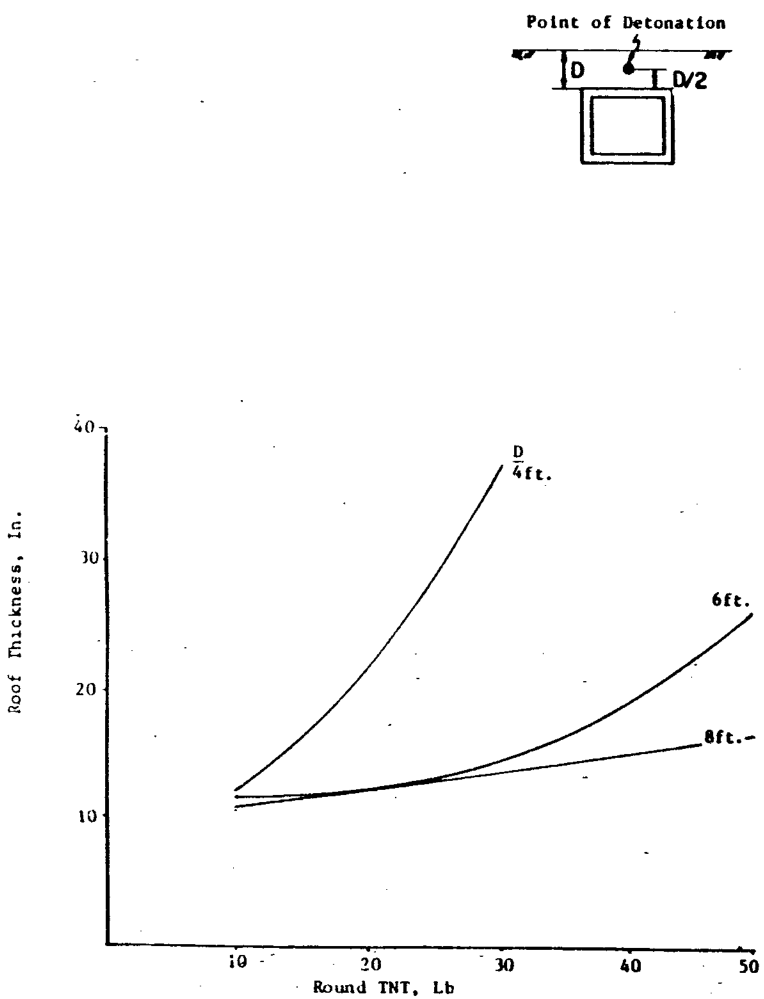

FIGURE E-2. ROOF THICKNESS--COVER RELATIONSHIP (RECTANGULAR).

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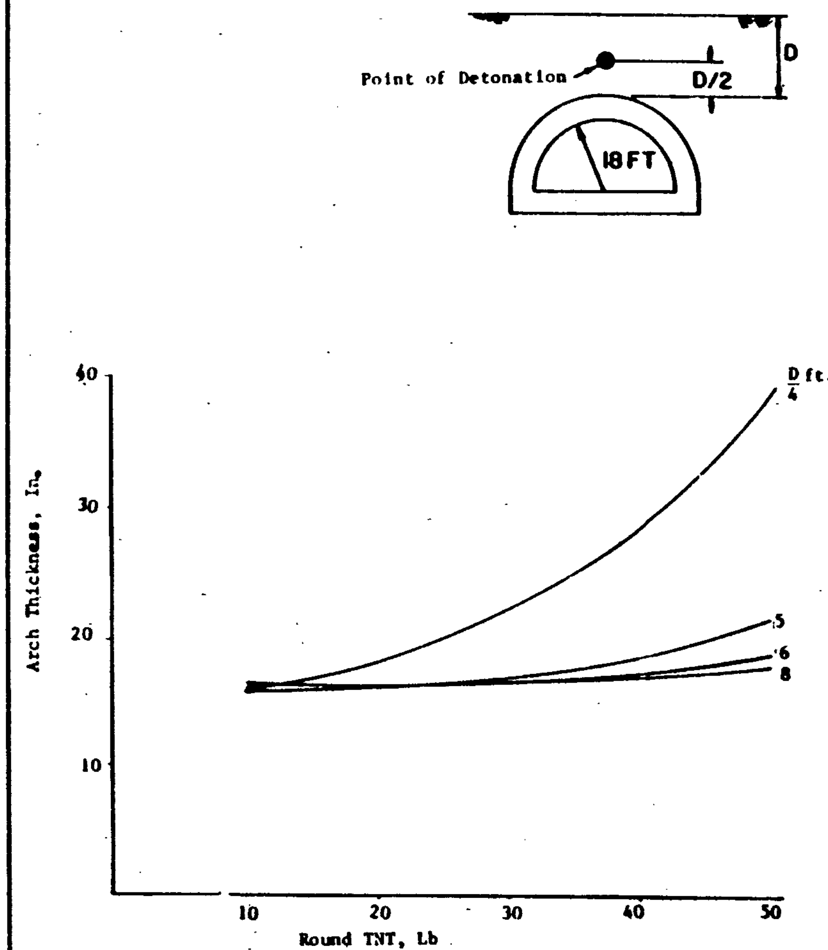

FIGURE E-3. ROOF THICKNESS--COVER RELATIONSHIP (SEMICIRCULAR CROSS SECTION).

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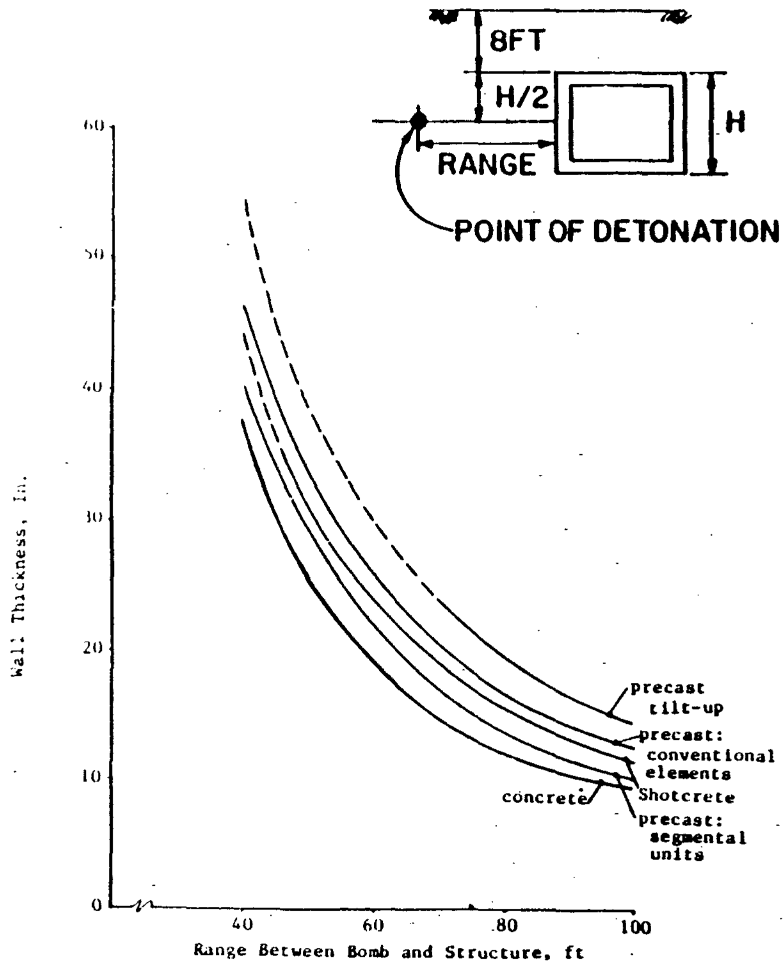

FIGURE E-4. WALL DESIGNS FOR RECTANGULAR SECTION.

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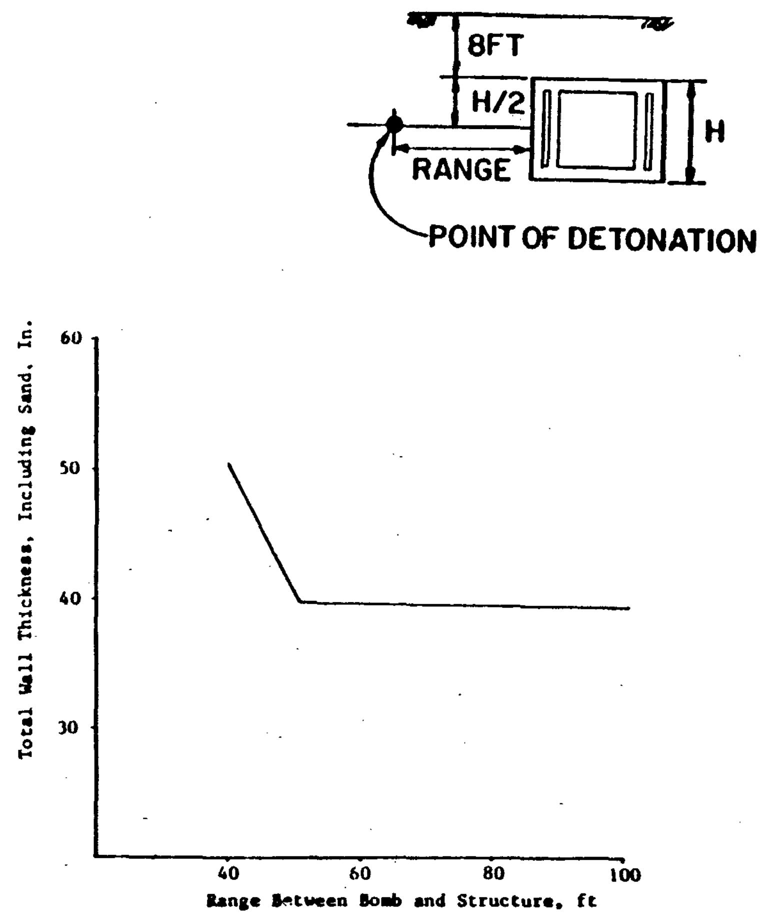

FIGURE E-5. WALL DESIGNS FOR DOUBLE-PANEL WALL SECTION.

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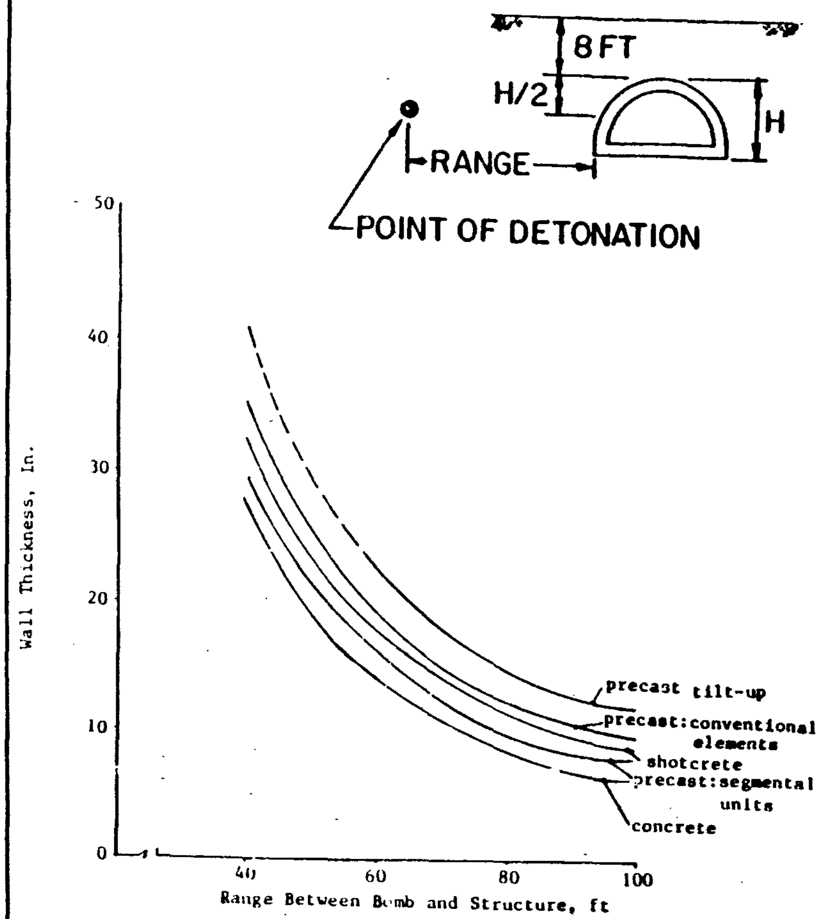

FIGURE E-6. WALL DESIGNS FOR CIRCULAR SECTION.

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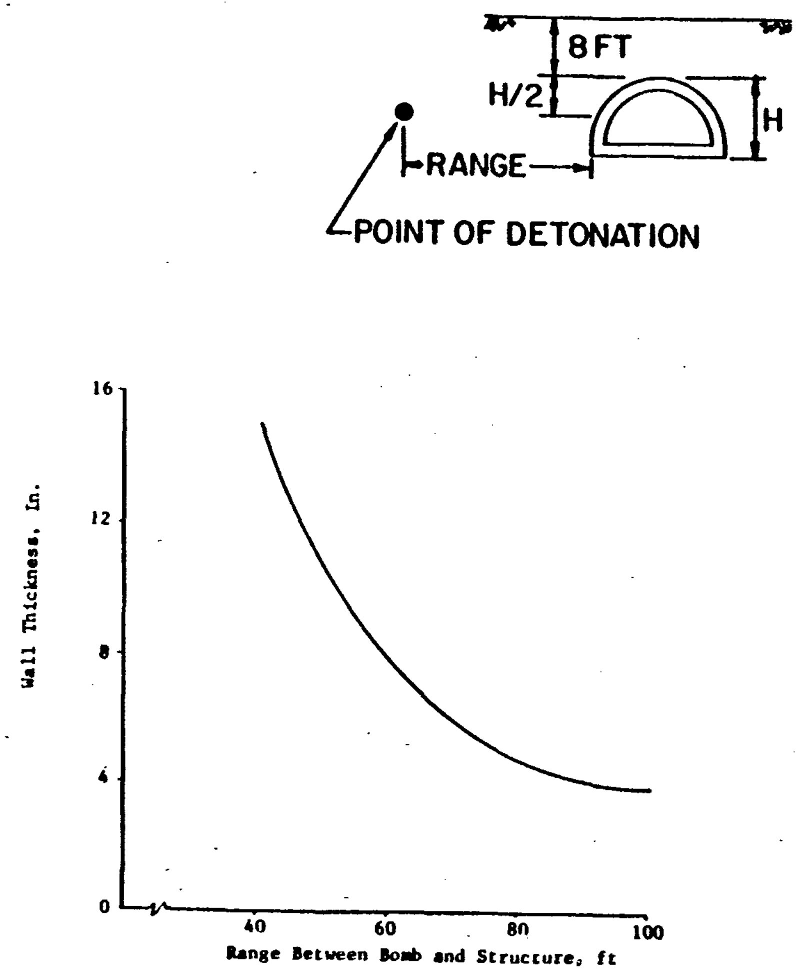

FIGURE E-7. WALL DESIGNS FOR COMPOSITE CIRCULAR SECTION.

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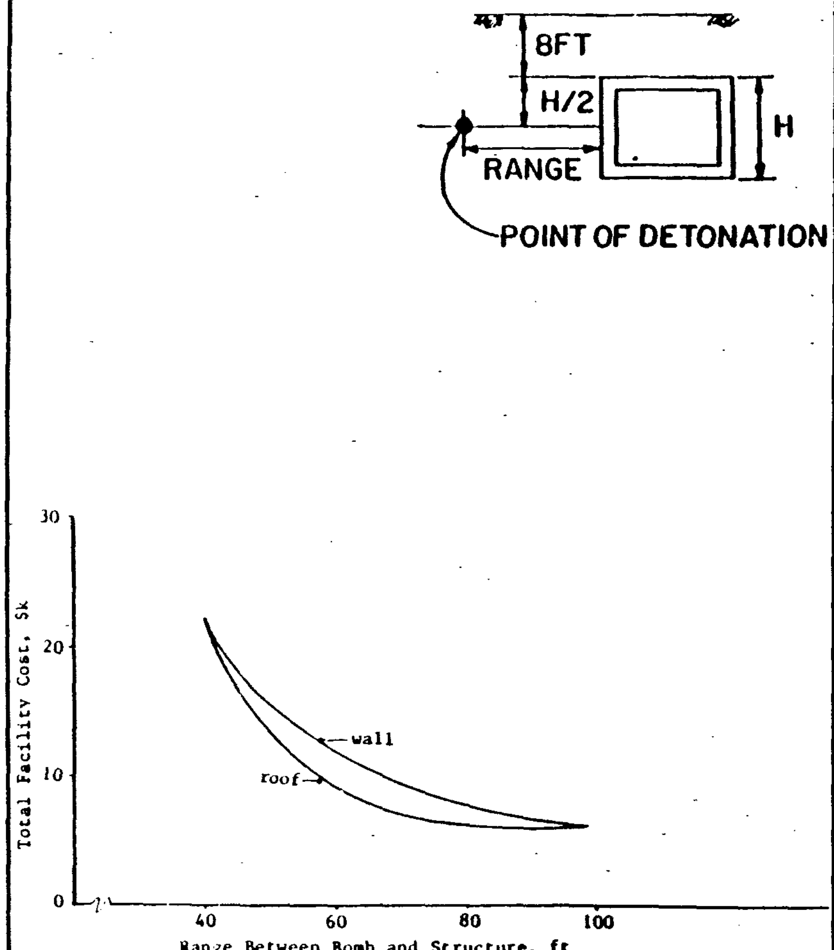

FIGURE E-8. WALL AND ROOF DESIGN FOR CONCRETE/PREFABRICATED BOX SECTION.

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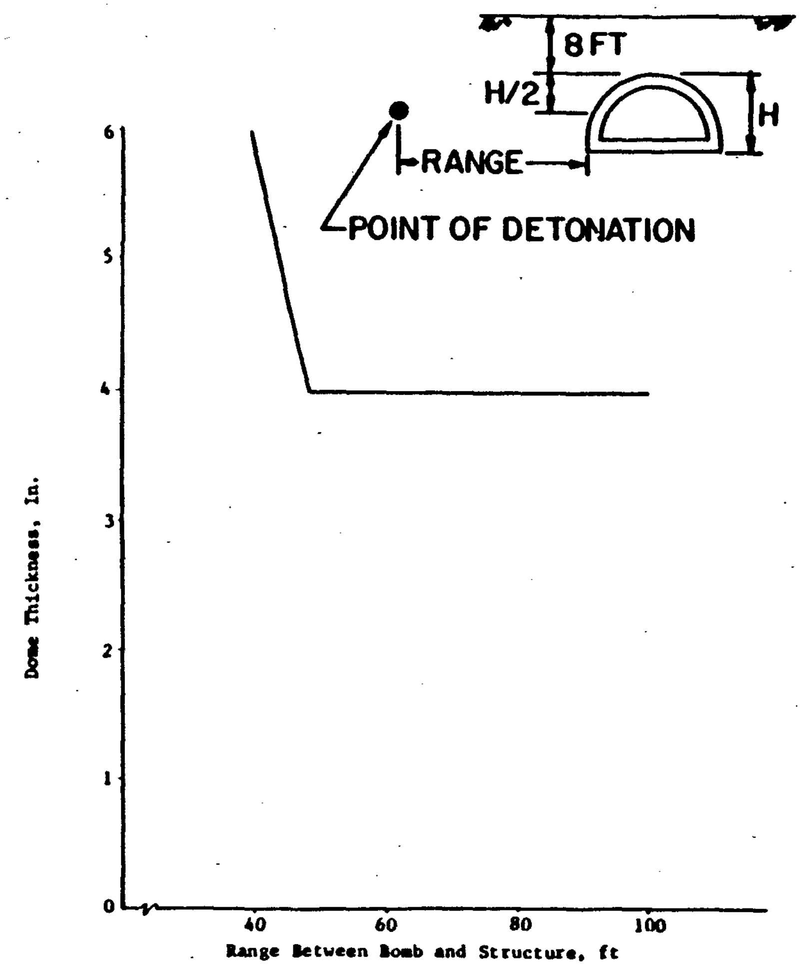

FIGURE E-9. WALL DESIGNS FOR DOME SECTION.

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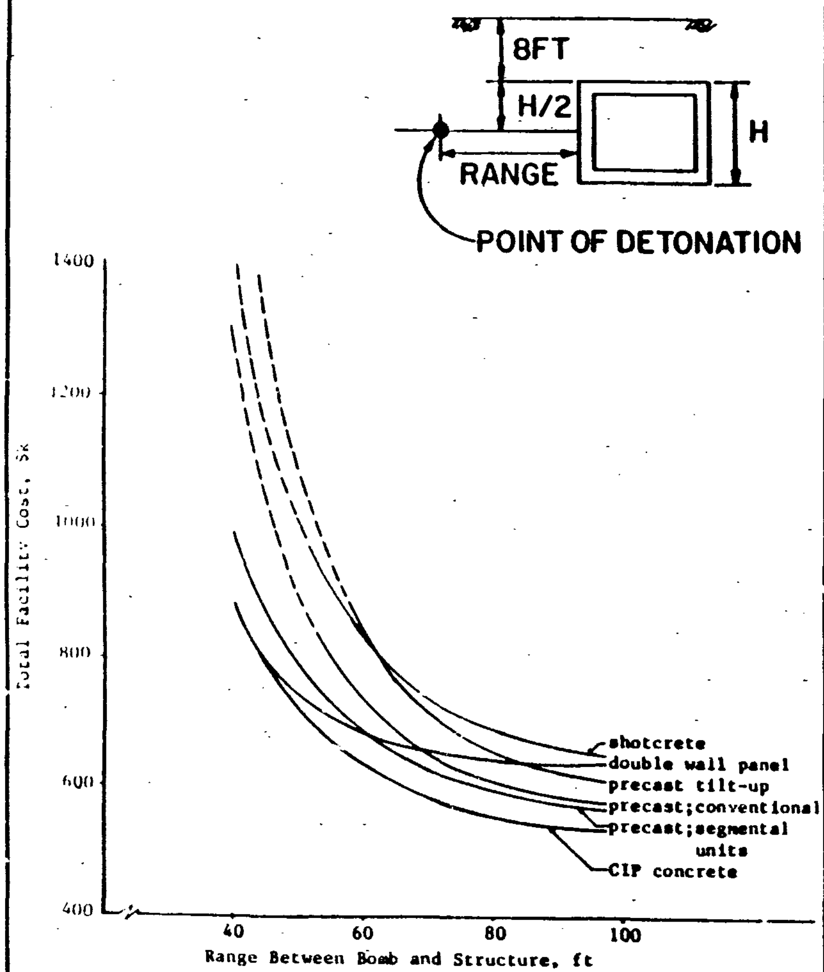

FIGURE E-10. TOTAL FACILITY COSTS FOR TRANSPORTABLE UNIT SHELTER, RECTANGULAR SECTION.

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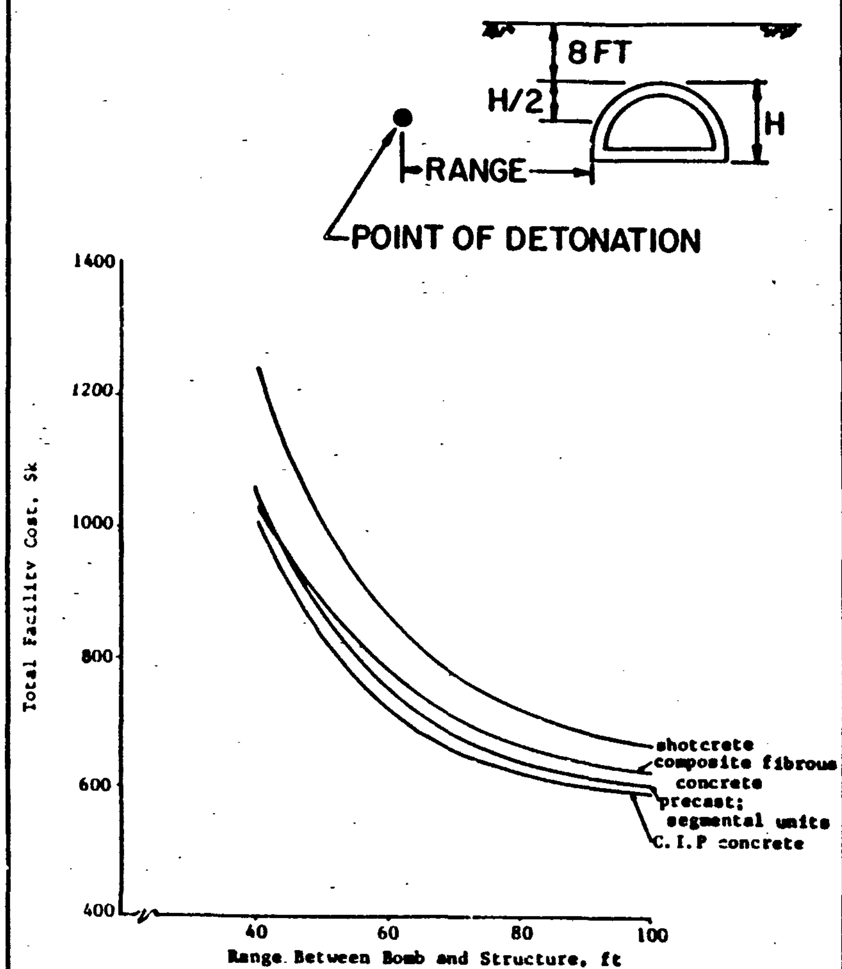

FIGURE E-11. TOTAL FACILITY COSTS FOR TRANSPORTABLE UNIT SHELTER, CIRCULAR SECTION.

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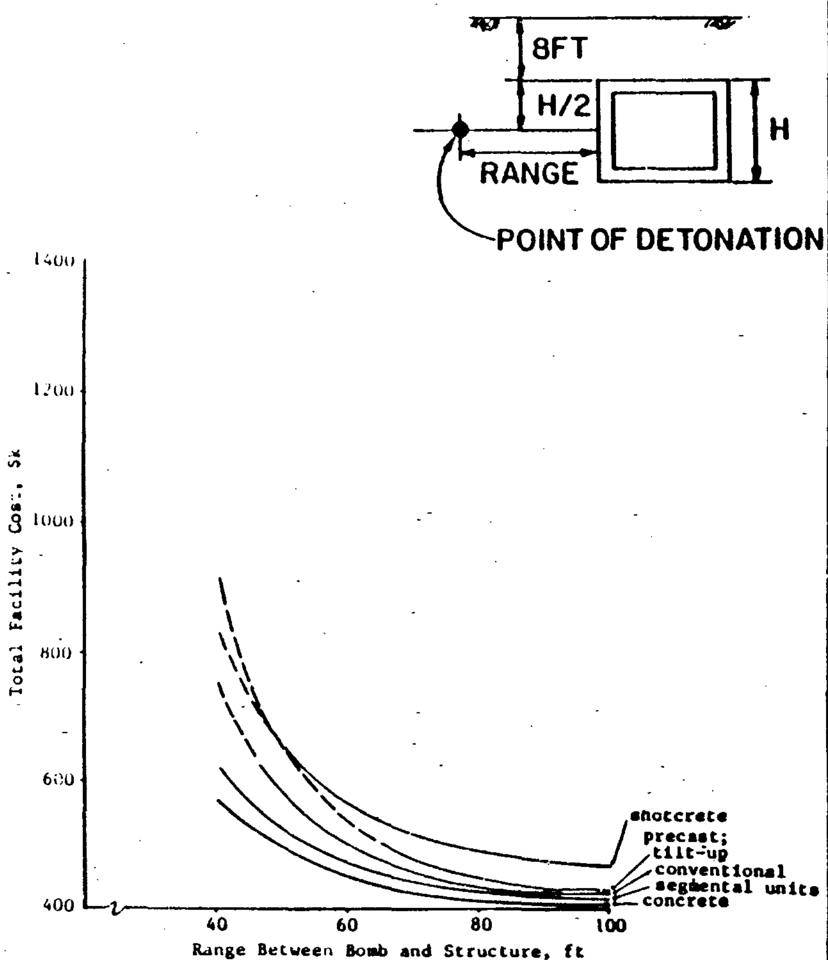

FIGURE E-12. TOTAL FACILITY COSTS FOR RECONSTITUTIONAL PACKAGE SHELTER, RECTANGULAR SECTION.

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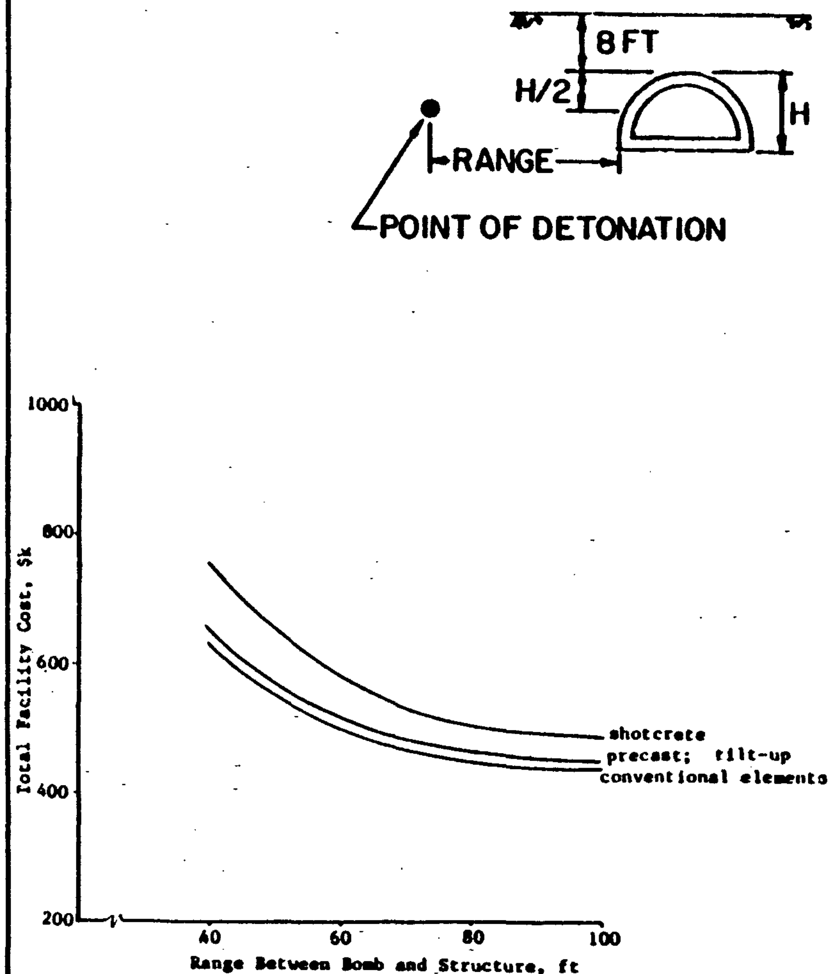

FIGURE E-13. TOTAL FACILITY COSTS FOR RECONSTITUTIONAL PACKAGE SHELTER, CIRCULAR SECTION.

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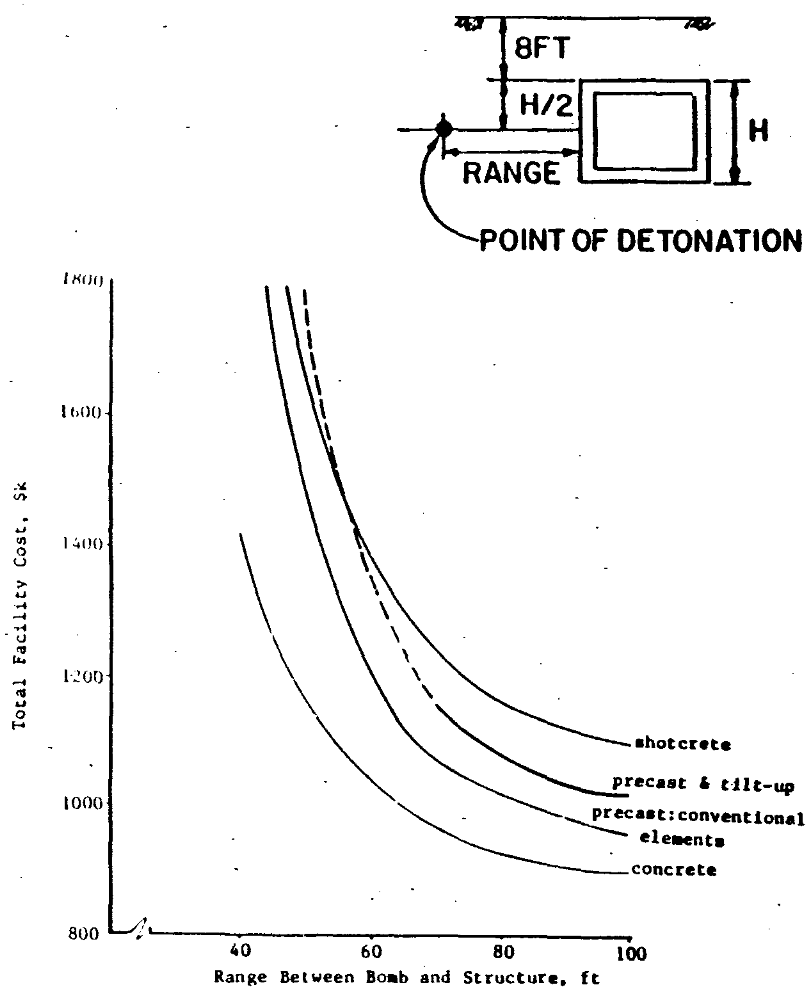

FIGURE E-14. TOTAL FACILITY COSTS FOR INTEGRATED OPERATIONAL AND TRANSPORTABLE UNIT SHELTER.

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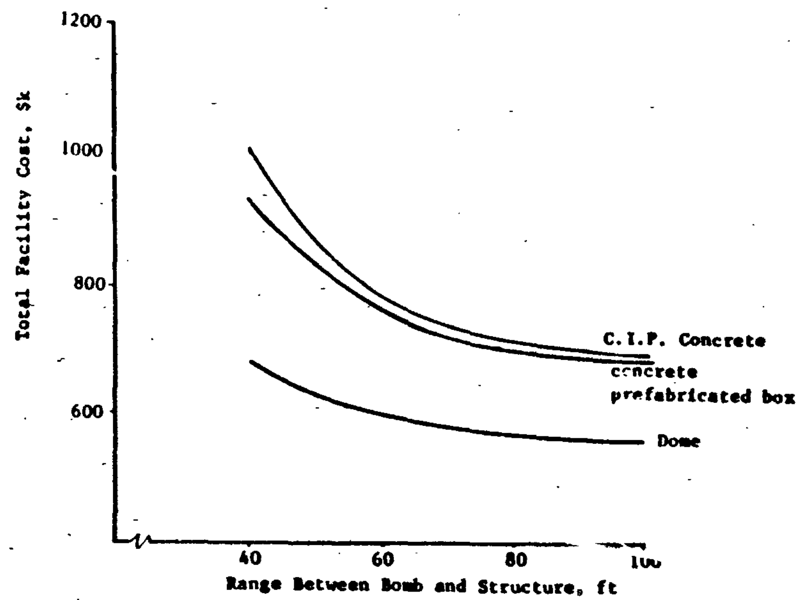

FIGURE E-15. TOTAL FACILITY COSTS FOR OPERATIONAL SHELTER.

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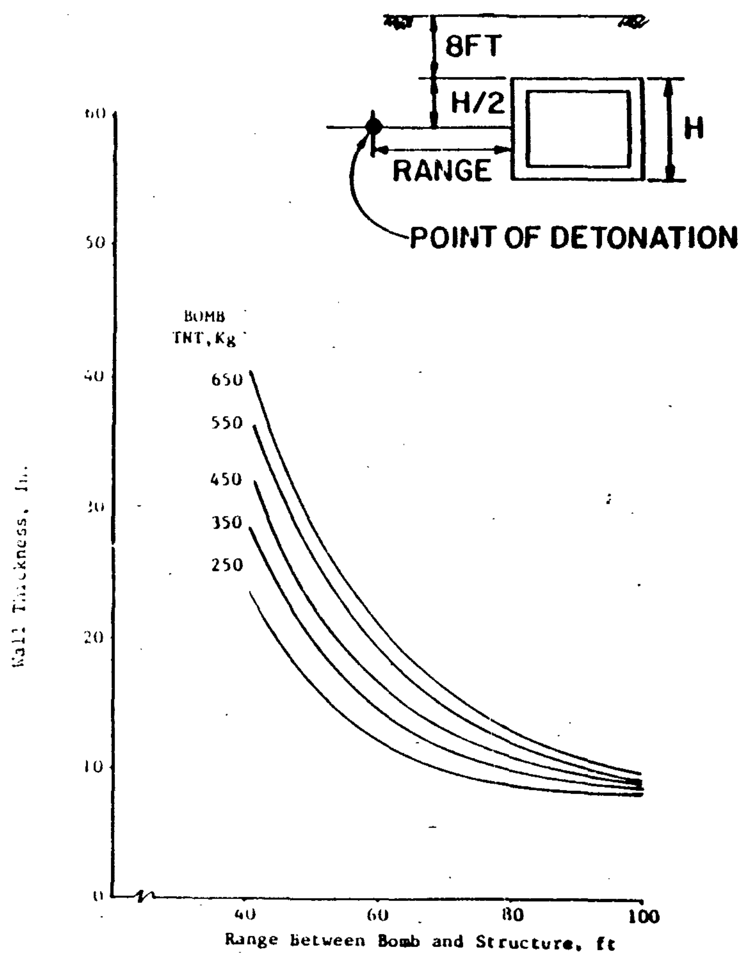

FIGURE E-16. TRANSPORTABLE UNIT SHELTER WALL THICKNESS RELATIVE TO AERIAL ORDNANCE THREAT.

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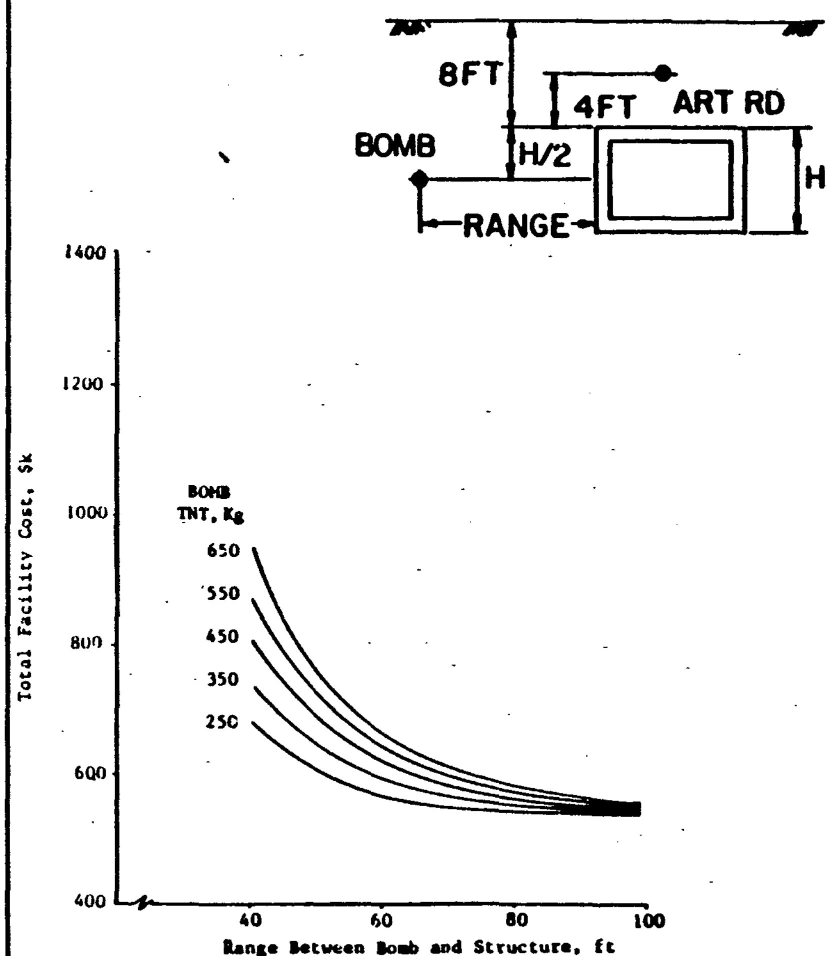

FIGURE E-17. TOTAL FACILITY COST FOR TRANSPORTABLE UNIT SHELTER RELATIVE TO AERIAL ORDNANCE THREAT.

guidance

CONCLUSIONS

The objective of this study was to identify facility configurations and construction techniques that would provide the DCS with alternative ways of constructing shelters to protect prepositioned communication equipment and operational space on installations subject to attack. The desired performance attributes for the proposed facilities were:

Low first cost--no greater than 1.5 times equivalent of nonhardened construction cost.

Rapid construction--no greater than 80 percent equivalent of nonhardened construction time.

Endurance--able to sustain direct hits by heavy armor/concrete piercing ground weapons and near misses by 1.1-ton aerial ordnance without loss of structural integrity or major damage to equipment and loss of personnel located inside.

Low operating cost--energy and maintenance cost no greater than 80 percent equivalent of nonhardened construction.

Two buildings were used to baseline the analysis: a preengineered metal building was taken as the least expensive nonhardened weather shelter available for the stored equipment, and the standard reinforced concrete ammunition storage igloo as the shelter meeting minimum requirements for mounding or burial. The igloo is used primarily to store explosives and to prevent sympathetic detonation of the stored explosives due to accidental detonation of explosives in an adjacent igloo. The igloo is designed to support a minimum earth cover, but significant external dynamic loading. The igloo needed to shelter the transportable unit is about 13.6 times the cost of the metal preengineered building; the ratio for the reconstitutional unit storage is about 22.4. This cost increase does bring slightly more protection than can be provided by the metal building; however, it adds little protection against the specified threat.

The standard igloo was assumed to be the baseline for comparative estimates. It is basically nonhardened and incorporates the mounding used in all of the alternatives. The cost limit for the transportable unit shelter would be about $1215K and about $770K for the reconstitutional unit shelter using the factor of 3 given in the desired performance attributes.

Several building configurations and construction techniques were investigated that would satisfy all four performance attributes. All shelters considered were designed to withstand the specified threat which would allow the 1.1-ton bomb to detonate as close as 40 ft from the exterior wall at a penetration depth equal to the wall's centerline, and to survive direct hits to the roof from 8-in. artillery rounds. If the bomb detonates closer than 40 ft, the shelter could be damaged by cratering action or by flying ejecta. Superhard structures would be required to withstand this more severe threat.

guidance

The transportable unit shelter can be constructed to withstand the 40-ft standoff distance for $885K to $1060K, about 2.19 to 2.62 times the cost of the baseline shelter. Shelters meeting the performance criteria are partially buried facilities of the following types:

- **Cast-in-place concrete rectangular cross section**
- **Cast-in-place concrete circular cruss section**
- **Fibrous concrete, insulating foam, and corrugated metal plate composite construction in a circular cross section**
- **Precast segmental units, rectangular cross section**
- **Precast segmental units, circular cross section**
- **Double wall panel, rectangular cross section.**

The composite construction approach could be constructed fastest since it does not require forms to be erected and removed or walls to be constructed using lifts.

The reconstitutional unit shelter can be constructed for $575K to $760K or 2.24 to 2.92 times the baseline shelter. The shelters meeting the performance criteria are partially buried facilities of the following types:

- **Cast-in-place concrete rectangular cross section**
- **Cast-in-place concrete circular cross section**
- **Precast segmental units, rectangular cross section**
- **Precast segmental units, circular cross section**
- **Shotcrete circular cross section**

The rectangular cross sectional shelter could be constructed fastest since it would use standard forms and conventional construction techniques.

The operational shelters can be constructed for $650K to $1415K or 1.11 to 2.43 times baseline facility cost. Shelters meeting the performance criteria are partially buried facilities of the following types:

- **Cast-in-place concrete integrated with the transportable unit storage in the rectangular cross section**
- **Cast-in-place concrete rectangular cross section**
- **Concrete/prefabricated box form construction**
- **Dome construction**

guidance

The concrete/prefabricated box form probably could be constructed fastest since it does not require special equipment or unique skills. However, there should be very little difference in construction times between the box forms and the dome.

All other configurations and construction techniques were found to be much more expensive than the alternatives selected above when designed to survive the defined threat.

All shelter concepts were designed to meet the low operating cost criteria by incorporating the following features:

1. Environmental control systems were designed on the basis that buried/mounded shelter interiors will be maintained at a constant ground temperature.

2. In the operational shelters, a chiller using well water as the cooling fluid will be installed rather than other cooling techniques that could require more equipment and maintenance.

3. The ventilation system for the operational shelter will be protected completely with a blast valve and can control the interior environment using outside air without use of the chiller. This system can be used when outside conditions permit. Under conditions that require CBR filtering, the blast-valve-protected ventilation system can draw 375 cfm into the cooling system to reduce the demand on the cooling system and to change the air in the shelter.

4. The mechanical and electrical systems will be very simple, requiring only basic controls.

5. The fuel storage tank will be elevated above the generators to eliminate the need for pumps and related equipment.

6. Waste will be discharged through a lift station, which is located in the mechanical room to make it easily accessible for maintenance.

7. The mechanical room floor in the operational sheltrr will be placed at the same level as the adjoining shelter floor to simplify equipment movement and maintenance.

8. Equipment storage shelter floors will be sloped to drain to the outside and provided with two depressed tracks to help guide vehicles as they are backed into the shelter.

Selection of the appropriate shelter concepts and construction techniques to be further investigated for design consideration at a specific geographical location is strictly the planners' responsibility. Enough comparative data have been provided, however, to assist planners in determining approximate construction cost or the impact of changing the assumptions underlying the cost estimates presented.

guidance

All power generation operations were moved outside sheltered areas to eliminate the need for high-maintenance, semihardened air intake and exhaust structures and for removing the resulting waste heat from the building. This provides the flexibility to perform maintenance on the portable generators either in place or at a remote maintenance shop.

Power generators were not included in the transportable unit and reconstitutional unit shelters. To reduce cost and maintenance requirements, it was assumed that the crews responsible for opening the shelters and removing the stored equipment would use portable generators. Using this technique, one portable generator set could be used to open all the shelters on an installation.

TABLE E-1

COST GROWTH FACTOR (CGF)

$$CGF = \frac{\text{Raw Inflation Index for Midpoint of Construction}}{\text{Raw Inflation Index for Midpoint of the Cost Estimate to be Adjusted}}$$

MONTHLY RAW INFLATION INDICES FOR MILITARY CONSTRUCTION
BASED ON OSD* RAW INFLATION RATES
BASE PERIOD 1983 : 10

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
80	.749	.750	.753	.758	.760	.765	.775	.783	.792	.804	.809	.810
81	.811	.812	.814	.819	.821	.825	.838	.848	.858	.873	.879	.879
82	.881	.882	.885	.890	.892	.897	.903	.917	.926	.939	.945	.945
83	.947	.947	.950	.955	.956	.961	.971	.979	.988	1.000	1.005	1.005
84	1.007	1.007	1.010	1.014	1.016	1.020	1.029	1.037	1.045	1.057	1.061	1.062
85	1.063	1.063	1.066	1.070	1.071	1.075	1.084	1.092	1.100	1.111	1.115	1.115
86	1.117	1.117	1.119	1.123	1.125	1.129	1.130	1.146	1.155	1.166	1.171	1.171
87	1.172	1.173	1.175	1.179	1.181	1.185	1.195	1.204	1.213	1.224	1.229	1.230
88	1.231	1.232	1.234	1.238	1.240	1.245	1.255	1.264	1.273	1.286	1.291	1.291
89	1.293	1.293	1.296	1.300	1.302	1.307	1.318	1.327	1.337	1.350	1.355	1.356
90	1.357	1.358	1.361	1.365	1.367	1.373	1.384	1.393	1.404	1.417	1.423	1.424

*OSD = Office of the Secretary of Defense.

TABLE E-2

AREA CONSUMPTION FACTOR (ACF) AND EXCHANGE RATE ASSUMPTIONS*

A. ACF=1.0 (Washington, DC)

B. Exchange Rates are AD/LEEEC forecasts for FY 83. When official exchange rates for the FY 83 MCP become available in late summer, AF/LFEEC will adjust MAJCOM prices accordingly.

CONUS

LOCATION	FACTOR
ALABAMA	89
Gulf Coast Area	1.00
ALASKA	1.40
Aleutian Islands	3.80
Campion	3.00
Cape Lisburne	3.50
Cape Newenham	3.20
Cape Romanzof	3.20
Clear AFS	2.20
Cold Bay	3.00
Dew Stations	3.80
Eielson AFB	2.10
Elmendorf AFB	1.90
Ft Greely (Big Delta	2.20
Ft Richardson	1.90
Ft Wainwright	2.10
Ft Whittier	2.10
Ft Yukon	3.00
Galena	3.00
King Salmon Airport	2.60
Kodiak	2.50
Kotzebue	3.50
Murphy Dome	2.10
Nome	2.30
Point Barrow	3.50
Sparrevohn	3.50
Tatalina	3.50
Tin City	3.20
	Scott AFB
ARIZONA	1.01
Davis-Monthan AFB	1.10
Ft Huachuca	1.20
Gila Bend AFS	1.15
Yuma P.G.	1.10

CONUS cont'd

LOCATION	FACTOR
ARKANSAS	.87
CALIFORNIA	1.11
Beale AFB	1.15
Castle AFB	1.15
Desert Areas	1.20
Edwards AFB	1.20
George AFB	1.20
March AFB	1.15
Mather AFB	1.15
McClellan AFB	1.15
Norton AFB	1.15
San Francisco Bay Area	1.20
Sierra Army Depot	1.20
Travis AFB	1.20
Vandenberg AFB	1.20
	Ft Richie
COLORADO	.98
Buckley ANGB	.98
Denver	1.10
CONNECTICUT	1.03
New London	1.20
DELEWARE	.99
DISTRICT OF COLUMBIA	1.00
FLORIDA	.95
Cape Canaveral AFS	1.15
Gulf Coast	1.00
Key West	1.20
Miama	1.15
Patrick AFB	1.15

LOCATION	FACTOR
GEORGIA	.86
Atlanta	1.00
Ft Stewart	1.02
King's Bay	1.02
HAWAII	1.20
Kauai	1.80
IDAHO	.96
Mt Home AFB	1.20
ILLINOIS	1.04
Glenview	1.06
Granite City Army Depot	1.20
Great Lakes	1.06
	1.20
INDIANA	.97
Gary	1.05
Grissom AFB	1.10
Indianapolis	1.05
IOWA	.97
KANSAS	.96
KENTUCKY	.94
LOUISIANA	.92
England AFB	1.05
Ft Polk	1.05
New Orleans	1.10
MAINE	.90
Northern Area	1.14

HQ USAF ANNUAL CONSTRUCTION PRICING GUIDE FOR FY 83 THRU 87 PROGRAMS AS OF MAR 81.

guidance

TABLE E-2, CONT'D

CONUS cont'd

LOCATION	FACTOR
MARYLAND	.96
Area Adjacdent to DC	1.00
....	1.10
Patuxent River ATC	1.10
MICHIGAN	1.02
Northern Area	1.15
MINNESOTA	.99
MISSISSIPPI	.99
Keesler AFB	1.00
Mississippi AAP	1.00
	OREGON
MISSOURI	.98
Ft Leonard Wood	1.20
St Louis	1.02
StLouis AAP	1.02
MONTANA	.95
Maistrom AFB	1.15
Northern Area	1.15
	Ellsworth AFB
NEBRASKA	.94
	TENNESSEE
NEVADA	1.05
Fallon NAS	1.20
Nellis AFB	1.15
Tonopah	1.60
	Dallas
NEW HAMPSHIRE	.92
Portsmith	.97
	Dugway Proving Ground

LOCATION	FACTOR
NEW JERSEY	1.04
NEW MEXICO	.96
Holloman AFB	1.05
NEW YORK	1.03
Griffiss AFB	1.06
Hancock Fld	1.06
Long Island	1.17
New York City	1.17
Plattsburg AFB	1.06
US Military Academy	1.17
	Puget Sound Area
NORTH CAROLINA	.84
Camp Lejeune	.95
Cherry Point	.95
Ft Bragg	1.00
Pope AFB	1.00
Seymour Johnson AFB	1.00
NORTH DAKOTA	.91
Northern Area	1.15
OHIO	1.02
OKLAHOMA	.94
Tinker AFB	1.00
....	1.01
PENNSYLVANIA	1.01
RHODE ISLAND	1.00
SOUTH CAROLINA	1.00

LOCATION	FACTOR
SOUTH DAKOTA	.92
....	1.15
....	.88
NAS MEMPHIS	1.00
TEXAS	.98
Carswell AFB	1.10
....	1.10
UTAH	.98
................................1.30	
Hill AFB	1.20
VERMONT	.91
Northern Area	1.07
VIRGINIA	.91
Area adjacent to DC	1.00
Dahlgren	1.00
Ft Lee	1.00
Norfolk-Newport News Area	1.00
WASHINGTON STATE	1.01
....	1.15
WEST VIRGINIA	.96
WISCONSIN	.98
WYOMING	.91

TABLE E-2, CONT'D

UNITED STATES JURISDICTIONS

LOCATION	FACTOR
CANAL ZONE	1.50
CAROLINA ISLANDS	
Truk	2.00
JOHNSTON ISLANDS	2.40
LINE ISLANDS	
Paymyra	2.00
MARIANA ISLANDS (GUAM)	2.00
MARSHALL ISLANDS	
Bikini	2.40
Eniwetok	2.40
Kwajalein	2.40
Majuro	2.40
Meck	2.40
MIDWAY ISLAND	2.40
PUERTO RICO	
Roosevelt Roads Area	1.50
SAN JUAN AREA	1.50
SAMOA	2.40
VIRGIN ISLANDS	1.30
WAKE ISLAND	2.20

OVERSEAS

LOCATION	FACTOR
ADMIRALTY ISLANDS	2.20
ALGERIA	1.30
ARGENTINA	1.90
ASCENSION ISLAND	2.50
AUSTRALIA	
North Coastal Areas	2.30
South Coastal Areas	1.10
AZORES	1.30
(ER = 55.00 Escudo/US $)	
BAHAMA ISLANDS	1.50
BELGIUM	1.50
(ER = 35.00 Franc/US $)	
BERMUDA	1.60
BOLIVIA	1.70
BRAZIL	1.50
BRITISH GUIANA	1.20
BRITISH HONDURAS	1.00
BRITISH WEST INDIES	
Antigus	1.40
Barbados	1.20
Trinidad	1.20
BURMA	1.40
CANADA	
(ER = 1.15 Dollar/US $)	
Labrador	1.40
Newfoundland	
Argentia	1.80
Inland Areas	2.20
North Inland Areas	
(Dew Line)	4.20
South Inland Areas	1.60
CHILI	1.50
CHRISTMAS ISLANDS	2.20
COLUMBIA	1.30
COSTA RICA	1.00
CUBA	
Guantanmo Bay	1.60
DENMARK	1.30
(ER = 6.50 Kroner/US $)	
DIEGO GARCIA	3.00
ECUADOR	1.50
EGYPT	1.50
(ER = 0.7 Pounds/US $)	
EL SAVADOR	1.00
FRENCH GUIANA	1.20
GERMANY, WEST	1.60
(ER = 2.00 Mark/US $)	
GREECE	1.40
GREENLAND	
Ice Cap	4.00
Narsarssuak	4.20
Sondrestrom AFB	3.10
GUATEMALA	1.00
ICELAND	3.00
INDIA	
Bombay	.90
ISRAEL	1.50
(ER = 8.6 Shekel/US $)	
US Labor	1.50
Local Labor	1.10
ITALY	
(ER = 1,000.00 Lira/US $)	
Northern	1.30
Southern (Naples)	1.10
JAMAICA	1.20

TABLE E-2, CONT'D

LOCATION	FACTOR
JAPAN	
(ER = 200.00 Yen/US $)	
Northern Area	1.70
Okinawa	1.60
Southern Area	1.60
Wakkanai	1.80
KOREA	1.05
(ER = 650.00 Won/US $)	
LIBERIA	.80
MEXICO	
Mexico City	1.00
MOROCCO	1.00
NETHERLANDS	1.60
(ER = 2.00 Guilder/US $)	
NEW ZEALAND	.80
NICARAGUA	1.00
NORWAY	1.40
OMAN	2.25
PAKISTAN	
West Karachi	1.20
PARAGUAY	1.60
PHILIPPINE ISLANDS	1.00
(ER = 7.50 Peso/US $)	
PHOENIX ISLANDS	
Canton Island	2.40
SAUDI ARABIA	
Dhahran	2.25
SPAIN	1.30
(ER = 85.00 Pesatas/US $)	
SRI LANKA	1.10
SWEDEN	1.20
THAILAND	1.00
TURKEY	1.60
(ER = 74.00 Lira/US $)	
UNITED KINGDOM	1.50
(ER = .43 Pounds/US $)	
URUGUAY	1.60
VENEZUELA	1.30
Thule	3.50

SECTION F CASE STUDY

DCA CIRCULAR 300-95-1

RS-75

CASE STUDY

function

To provide a semihardened shelter for an AUTODIN facility that can maintain operations in areas subject to attack using the design concepts developed in Section D.

policy/sop

policy/sop

1. The facility will provide the same functional spaces as now designed into unhardened AUTODIN facilities. Maximum facility population is estimated at 30.

2. Site security will be external to the facility and installed/monitored by others. Space will be provided for security and access control.

3. The facility will be able to operate on a continuous, uninterruptible basis without external support for at least 96 hours.

4. The design, siting, and construction of external facilities are not to be considered in this study.

5. The facility should provide for the command and communication circuits from the unhardened communication center as well as needed circuits to the remote facilities.

6. The base power supply will be the primary source for the facility. A hardened uninterruptable power source (UPS) will be provided for temporary backup and portable generator sets will be provided for permanent backup.

issues and assumptions

1. Siting

Facilities should be located away from primary targets (e.g., aircraft, runways, weapon systems, ammunition dumps) to reduce the possibility of collateral damage from an attack. It has been assumed that the facility is not a prime target and will be subjected only to bombs intended for other targets. The facility can be located on- or off-post as needed to provide adequate separation from prime targets. If located off-post, the cost of providing and maintaining perimeter security must be considered in planning.

Shelter concealment has not been considered since construction can be observed easily by satellite.

Depending on the terrain, the facility can be constructed either on the surface and mounded, partially buried and mounded, or totally buried. If possible, the facility should be sited to provide an entrance sloping away from the facility. Advantage should be taken of the natural contour of the land. Foundation drainage is required to control groundwater.

2. Facility configuration

The facility has been designed using two of the alternatives discussed in Section D: (a) the rectangular shape with longitudinal interior load bearing walls and short roof spans and (b) interconnected hemispherical domes. Floor elevations in both configurations will be constant. Structural slabs below each raised floor area will be depressed to provide adequate plenum volume and will be sloped for drainage.

Blast doors for personnel and equipment movement will be designed to withstand overpressure and debris from the specified threat. These horizontal sliding doors will be protected in structural concrete pockets and will be operated electrically. The roofline will be extended to protect the doors from direct hits and to provide weather protection for the portable generators sets in their operating positions. The blast doors' design will consider the reflected effect of a blast within the enclosed area.

Interior fire-rated doors will be used to isolate areas of the facility for fire and smoke control.

Vents with fire dampers will be provided in the load bearing walls as needed to promote air circulation. Air will be exhausted to the exterior through a blast valve.

Uncovered concrete floors will be treated with a sealant to reduce dust, and vinyl floor covering will be provided in all other areas. The raised floor will be designed for computer room applications and expected loads. A dropped ceiling will be used in the rectangular configuration to cover the overhead air handling units, chilled-water lines, and ductwork. In the dome configuration, air handling units will be mounted in vertical shafts located in the center of each dome. Chilled-water lines will be placed under the floor.

Issues and assumptions

Exterior wall and roof surfaces will be waterproofed with a sprayed-on material or single-ply membrane and covered with insulation board before backfilling.

3. Access

Personnel access to the facility will be through the security control area. Decontamination of personnel entering the facility was not a design consideration. Two emergency exits to grade have been provided.

The emergency exits will be placed as shown in Figures F-1 and F-2 to take advantage of two structural walls' intersection. Each exit will consist of a tube extending to the surface, filled with sand to ensure continuity of the protective layer over the facility. To use the exit, personnel will release the lower door, allowing the sand to fall into the facility, climb up the ladder in the tube, and release the weather cap at the surface. Two wall-hung ladders will be provided to allow personnel to release the inner door from one side to avoid the load of falling sand.

4. Electrical power

The facility will require power for operations and environmental control. The base power system will be the facility's main power source. A rotary UPS will be used to ensure power availability over short periods of interruption. During an attack, all operations would cease and battery-operated emergency lights would provide illumination after the base power is lost. After an attack, operations would begin again once the portable generators are moved outside and brought online. The generators, stored in the mechanical room, would be moved to their exterior operating spaces, connected to the fuel and power supply lines, and put into operation.

The estimated power requirement is 400 kW based on the 177-kW load criteria plus the environmental control system. This requirement can best be met by two 200-kW portable diesel generator sets. A buried fuel storage tank with a 6000-gal capacity will provide for 7 days of continuous operations.

5. Environmental control

Operational cooling will be provided by a 50-ton groundwater-cooled chiller, a chilled-water distribution system, and a distributed system of air handling units. Water will be taken from one well, passed through the chiller and returned to the ground through a second well. Two wells will provide a more reliable water source for the facility and, in case of pumping problems, cooling water could be wasted to the sewage lagoon or just to the outside.

Issues and assumptions

The mechanical equipment room will have an air handling unit (AHU) and distribution system for meeting low cooling loads and distributing outside air throughout the operational space. Chilled water AHUs will be located above the dropped ceilings or in the vertical shafts in the operational spaces to carry the rest of the load. Distributed AHUs could be floor-mounted if space were available. The AHUs can be used to meet the cooling requirements efficiently as the loads vary.

Outside air will be ducted into the facility at 450 cfm through a blast valve and CBR filter. This approach will produce a positive pressure in the facility, which will reduce infusion of contaminants from the outside. To reduce operating costs, an outside air system rated at 10,000 cfm will be provided for economic cooling when conditions permit. This system uses a blast valve for drawing in outside air, but does not have a CBR filter. The air will be exhausted by a pressure differential through the blast valve.

The mechanical equipment room contains one AHU with a CBR filter, chiller, chilled-water circulation pumps, compressor for control systems, and a sanitary sewage lift station.

6. Water and waste disposal

Water will be supplied from a ground well and pressure tank to meet both potable and cooling water requirements. Cooling water will be returned to the ground through a second well. Two wells will ensure a secondary water source in case of a failure in the primary system. Cooling water will be wasted to the outside through the wastewater system if it is not possible to return it to the ground through one of the wells.

Wastewater will be discharged into the sewage lagoon through the lift station located in the mechanical room. The facility's successful operation depends on the ability to discharge waste. Therefore the lift station will be placed inside the shelter for protection. (An unprotected lift station located near the lagoon would require the gravity pipe to be buried deeply.) After an attack, if the discharge pipe is blocked (damaged or destroyed), the lift station can be used to pump waste to the surface through a flexible hose. The lagoon will be designed based on the expected wastewater flow. If cooling water is discharged through the system, the lagoon will be allowed to overflow until system problems can be solved.

Flexible connections will be used in the piping systems near the facility to reduce possible damage from ground shock.

7. Security

It has been assumed that project planners will satisfy site security requirements and, thus, this information has not been considered here. Security personnel will provide interior security. Space will be provided in the facility for an access control station. A small, secure space has been provided to store a few incendiary devices for destroying classified documents.

activities	personnel	equipment
1. Establishing work-stations.	1. Equipment installers.	1. Heating, ventilation, and A/C equipment.
2. Installing communication equipment initially, including integration and checkout.	2. DEH personnel to fill and maintain the storage tanks.	2. Temperature and humidity sensors and controls.
3. Filling water and fuel storage tanks.	3. Inventory personnel.	3. Communication equipment.
4. Checking backup power.	4. Equipment test, operation, and evaluation personnel.	4. Portable electronic testing equipment on movable carts.
5. Testing environmental control equipment.	5. DEH building equipment maintenance personnel.	5. Fire alarms and sensors.
6. Monitoring internal environment and status of storage tanks.		6. Security system components.
7. Performing periodic operational checks.		7. Water pumps and supply equipment.
8. Maintaining equipment.		8. Sanitary lift station.
9. Charging and maintaining UPS batteries.		9. Fuel storage tank and distribution.

activities	personnel	equipment

requirements	criteria	commentary
1. Adequate space.	1. Size facility to provide space equal to that shown on the DCA-furnished layout drawings for an AUTODIN switch. There are no requirements for living quarters, rest areas, food storage/preparation, or general storage.	
2. Structure.	2. Semiharden facility to withstand overpressures due to blasts from near misses by bombs exploding at ranges of 75 ft or more.	
3. Openings.	3. Provide two emergency escape exits to the surface. Doors between the communication equipment room and other spaces will be fire-rated. Provide one hardened blast door for personnel and one for equipment movement as access to the facility from the main tunnel entrance. Openings will be provided in the roof over the generator operating area for passing exhaust to the exterior to prevent the buildup of fumes in the entrance area.	
4. Ventilation system and humidity control.	4. Install filters to remove dust from the incoming air. Ventilation and humidity requirements will conform to existing criteria for operational spaces. Provide a CBR filter in the ventilation air system for use during the button-up period. Provide openings covered with fire dampers for air circulation between the major areas.	
5. Illumination.	5. Provide standard ADP and office area lighting levels (50 lux).	
6. Power.	6. Provide 177-kW supply for all lighting and communications equipment operation. Provide 110-V a.c. electrical outlets on 10-ft centers throughout the facility for equipment. Provide temporary backup power by a battery-based rotary UPS. Provide permanent backup with portable generators. Energy needed to reject the waste heat, etc. will add approximately 175 kW to the equipment load, raising the needed power generation capacity to approximately 400 kW. Size fuel storage and the cooling system to support at least 7 days of continuous operations without external support.	
7. Heating and cooling.	7. Install equipment to maintain the environment within the standard temperature range for operational spaces. Well-water cooling systems will be used as the primary source. The plenum under the equipment floor will be used for distributing the air supply. Space will be provided above the dropped ceilings for returns. A water source heat pump will be used in conjunction with the well water circulating system to heat the facility.	
8. Survivability protection.	8. Provide HEMP and CBR control. The facility must be capable of being totally buttoned-up for 4 hours without external support. The environment must be maintained to support personnel and equipment in an operational mode during the button-up period.	

requirements	criteria	commentary
9. Fire protection.	9. Install a Halon system below the equipment floor. Install a dry-pipe water sprinkler system with manual override on the ceilings.	
10. Security.	10. Provide space for controlling personnel access to the facility.	
11. Potable water.	11. Allow for approximately 1350 gal/day potable water for operators. Provide water treatment equipment if needed.	
12. Sanitary waste removal.	12. Provide a system for disposing of sanitary waste outside the facility	
13. Drainage.	13. Provide good drainage to control ground- and surface water at the site.	

guidance

Analysis

The facility design and cost estimates were developed using the same assumptions and processes discussed in Section E, with one exception: the location factor was changed to 1.50 to reflect the cost of construction in Belgium.

Findings and conclusions

The rectangular cast-in-place concrete configuration can be constructed for $1810K, or $215/sq ft. The fibrous concrete multidome configuration can be constructed for $1786K, or $207/sq ft.

The dome configuration should have the shortest construction time, considering the use of inflated forms, spray-applied polyurethane foam form material, and fibrous shotcrete.

The dome-based facility could be constructed in a variety of general configurations. However, the general rectangular shape appears to be the best, considering both room layout and earthwork requirements.

The facility's total cost may be reduced by reconsidering floor space requirements in the nonequipment areas. The spaces indicated are based on those provided in a low-cost unhardened facility. In the dome-based facility, the space may be used more efficiently by reconsidering the passageway in the toilet area and the waiting rooms as well as possible use of storage platforms. Overhead storage space could be constructed to take advantage of the 14-ft ceiling height.

guidance

guidance

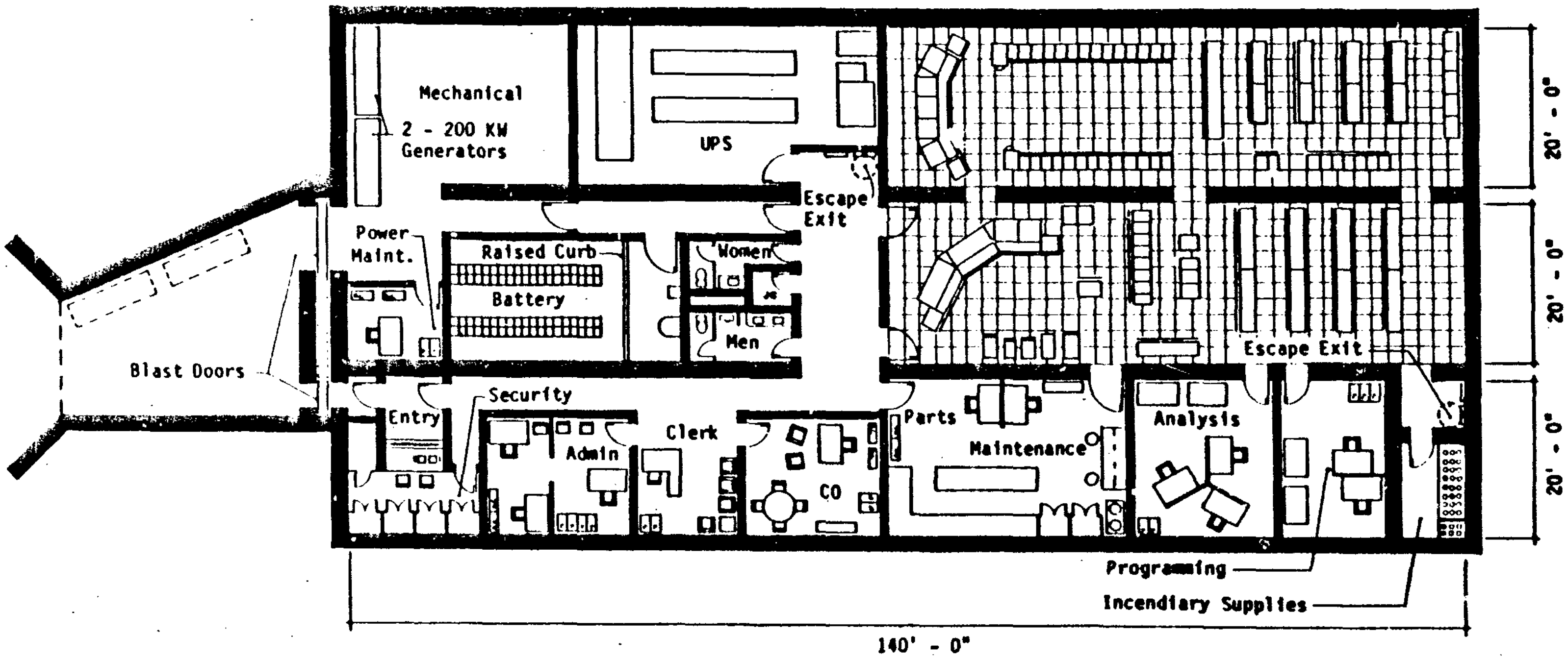

FIGURE F-1. AUTODIN SWITCH FACILITY PLAN--RECTANGULAR CONFIGURATION.

guidance

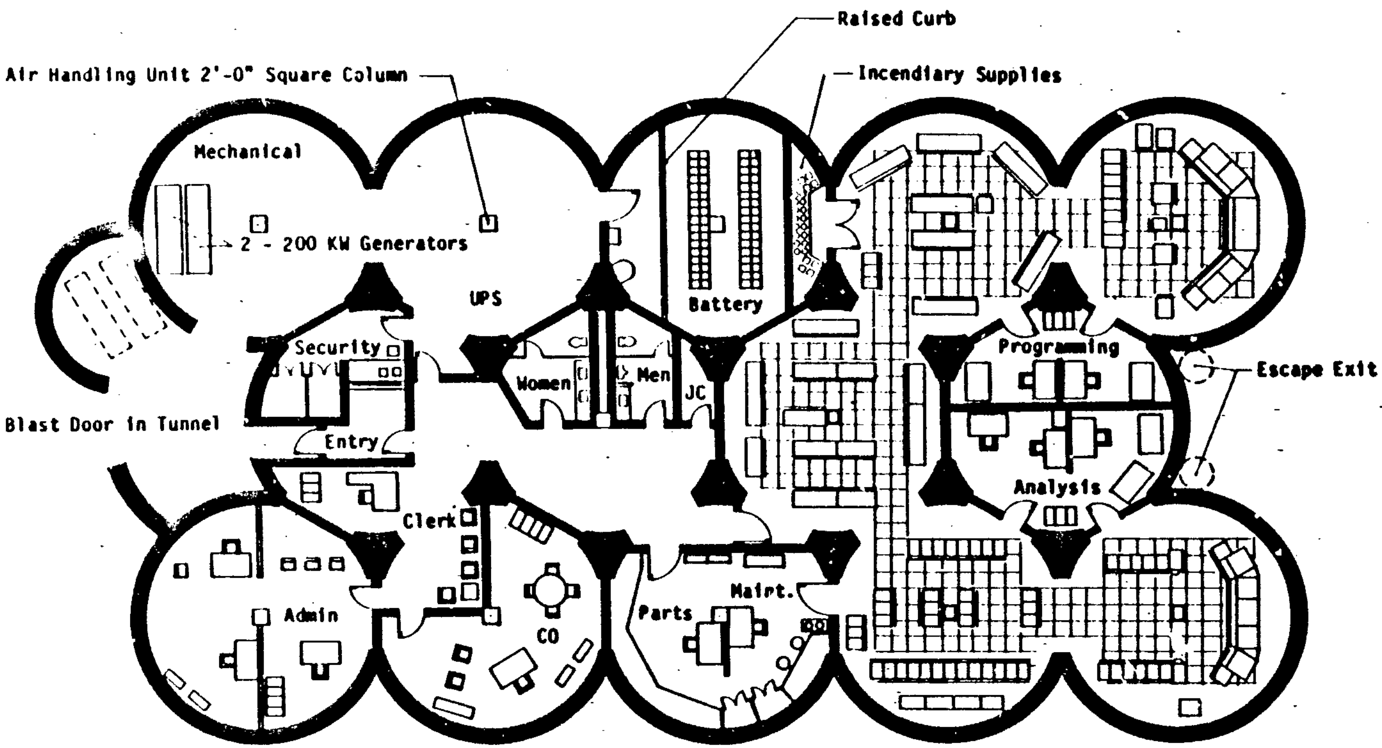

FIGURE F-2. AUTODIN SWITCH FACILITY PLAN--DOME CONFIGURATION.

METRIC CONVERSIONS

1 ft = .308 m

1 in. = 2.54 cm

1 sq ft = .092 m^2

1 cu ft = .028 m^3

1 cu ft/min = .467 mm^3/sec

1 gal = 3.785 L

1 Lux = 1 lumen/m^2

1 hp = .745 kW

1 lb = .453 kg

1 Ton = 906 kg

1 psi = 6.89 Pa

APPENDIX

COST ESTIMATES

APPENDIX A COST ESTIMATES

Baseline - Conventional Construction

Item #	Description	Est. Quan.	Unit	Bare Costs Mat.	Bare Costs Inst.	Bare Costs Total	Total incl. O&P
1	DCS TRANSPORTABLE UNIT Low Rigid Frame Bldg.						
					All Costs:	Per S.F.	
	Fdn. 4' depth, 12" x 16" footer			.82	.82	1.65 1.82	2.00
	6" conc. slab, wire mesh reinf.			.82	.82	1.65 1.82	2.00
	Pre-engineered Bldg. Steel frame, gal. steel wall Panels, gal. steel roof			4.12	1.65	5.78 6.36	7.00
	Insulation			.50	.32	.82 .9	1.00
				Total Cost/S.F. =		12.00	
				Total Cost =		$29,670	
	DCS RECONSTITUTIONAL PACKAGE						
					All Costs:	Per S.F.	
	Fdn. 4' depth, 12" x 16" footer			.82	.82	1.65 1.82	2.00
	6" conc. slab, wire mesh reinf.			.82	.82	1.65 1.82	2.00
	Pre-engineered Bldg. Steel frame, gal. steel wall Panels & Roof Panels			4.71	1.88	6.60 7.27	8.00
	Insulation			.5	.32	.82 .9	1.00
				Total Cost/S.F. =		13.00	
				Total Cost =		$11,440	

Baseline - Reconstitutional Package Storage - Igloo - Condition A

Item #	Description	Est. Quan.	Unit	Bare Costs Mat.	Bare Costs Inst.	Bare Costs Total	Total incl. O&P
1	CONCRETE:						
	Arch	65	C.Y.	6110	9100	15,210	19,825
	beams	2.5	C.Y.	345	550	895	1175
	Slab	1000	S.F.	940	720	1660	1980
	Footings	35	C.Y.	2625	1330	3955	4725
	Fdn. Walls (Front & Back)	11.5	C.Y.	966	1380	2346	3048
	Walls (Front & Back)	40	C.Y.	3360	4800	8160	10,600
	Fdn. Walls (Sides)	21	C.Y.	1617	1995	3612	4620
	Vent Shaft	21	C.Y.	2079	3570	5649	7455
						Subtotal	53,428
2	REBARS:						
	Footings	3.75	Tons	1856	1144	300	3750
	Fdn. Walls	9.5	Tons	4703	2043	6745	8265
	Walls and Arch	16.7	Tons	8266	3591	11,857	14,529
	Floor Slab	1.0	Ton	485	280	765	960
						Subtotal	27,504
3	FORMS:						
	Footings	1461	SFCA	424	1753	2177	2951
	Keyway	200	L.F.	14	56	70	96
	Beams	300	SFCA	126	447	573	774
	Floor Slab	150	L.F.	23	146	168	231
	Fnd. Wall	546	SFCA	251	972	1223	1660
	Front & Rear Wall	2396	SFCA	1102	4265	5367	7284
	Arch & Side Walls	5760	SFCA	3514	15,437	18,950	25,862
						Subtotal	38,858

Reconstitutional Package Storage--Igloo, cont'd

4	FINISHING:						
	Floor:						
	Screed	1000	SF	-	160	160	220
	Trowel	1000	SF	-	310	310	420
	Walls	3000	SF	210	1440	1650	2250
						Subtotal	2890
5	SECURITY DOORS	UNIT PRICE - 124,000					
6	MOISTURE PROTECTION:						
	Slab Vapor Barrier	10	Sq	54	40	94	116.5
	Membrane Waterproofing* (Arch)	2000	S.F.	1660	1280	2940	3700
	Membrane Waterproofing (Front & Walls)	2400	S.F.	1992	1766	3758	4670
	Caulking	50	L.F.	33	42	75	96
	*3-ply fabric					Subtotal	8583
7	SITE WORK:						
	Excavation (Bldg)	148	CY	188	175	363	459
	Footings	180	CY	193	243	436	560
	Excavation (Road)	65	CY	70	17	87	102
	Compacted Backfill	948	CY	958	304	1261	1498
	Road - 3" deep stone	89	SY	75	26	101	116
	Erosion Control	517	SY	285	78	362	424
	Fine Grading & Seeding	517	SY	93	465	558	739
						Subtotal	3878
						TOTAL	$259,161

Baseline - Reconstitutional Package Storage - Igloo - Condition B

Item #	Description	Est. Quan.	Unit	Bare Costs Mat.	Bare Costs Inst.	Bare Costs Total	Total incl. O&P
1	CONCRETE: Same as condition A except; subtract portal wall portions,					A Subtotal	53,428
	Footings	2	C.Y.	150	76	226	- 270
	Foundation Wall	2	C.Y.	168	240	408	- 530
						Subtotal	52,628
2	REBARS: Same as condition A except:					A Subtotal	27,504
	Footing	.1	Tons	49.5	30.5	80	- 100
	Fdn. Walls & Walls	.34	Tons	169	73	242	- 280
						Subtotal	27,108
3	FORMS: Same as condition A except:					A Subtotal	38,858
	Footings	150	SFCA	44	180	224	- 303
	Fdn. & Walls	92	SFCA	43	164	207	- 208
						Subtotal	38,275
4	FINISHING: Same as condition A						2,890
5	SECURITY DOORS						124,000
6	MOISTURE PROTECTION: Same as condition A except					A Subtotal	8583
	Membrane Waterproofing	50	S.F.	42	32	74	- 93
						Subtotal	8,490
7	SITE WORK:						
	Excavation (Bldg)	553	CY	702	653	1355	1714
	Excavation (Road)	554	Cy	593	144	737	865
	Compacted Backfill	454	CY	459	145	604	717
	Roadway 3" deep stone	211	SY	180	61	241	275
	Erosion Control	476	SY	262	72	333	390
	Fine Grading & Seeding	476	SY	86	428	514	681
						Subtotal	4,642
						TOTAL	$258,033

Baseline - Reconstitutional Package Storage - Igloo - Condition C

Item #	Description	Est. Quan.	Unit	Bare Costs Mat.	Bare Costs Inst.	Bare Costs Total	Total incl. O&P
1	CONCRETE:						
	Same as condition A except:					A Subtotal	53,428
	Footings	14.8	C.Y.	1111	563	1674	- 2000
	Fdn. Wall	4.7	C.Y.	398	568	966	- 1255
	Portal Wall	19	C.Y.	1596	2280	3876	- 5035
						Subtotal	45,138
2	REBARS:						
	Same as condition A except					A Subtotal	27,504
	Footing/Fdn.	.77	Tons	331	234	616	- 770
	Portal Wall	.71	Tons	352	153	504	- 3113
						Subtotal	26,116
3	FORMS:						
	Same as condition A except:					A subtotal	38,858
	Footing (Portal)	530	SFCA	154	636	790	- 1071
	Fdn. Wall (Portal)	250	SFCA	115	445	560	- 760
	Portal Wall	1024	SFCA	471	1822	2294	- 3113
						Subtotal	33,914
4	FINISHING						
	Same as condition A						2,890
5	SECURITY DOOR						124,000
6	MOISTURE PROTECTION:						
	Same as condition A except:					A subtotal	8583
	Membrane Waterproofing	512	S.F.	425	328	753	- 948
						Subtotal	7,635
7	SITE WORK:						
	Excavation (Bldg)	1477	C.Y.	1876	1743	3619	4579
	Excavation (Road)	3111	C.Y.	3951	3671	7622	9644
	Compacted Backfill	855	C.Y.	864	274	1137	1351
	Roadway - 3" deep stone	444	SY	378	129	507	578
	Erosion Control	407	SY	224	61	285	334
	Fine Grading & Seeding	407	SY	74	366	440	582
						Subtotal	17,068
						TOTAL	$256,761

Baseline - Transportable Unit Storage - Igloo - Condition A

Item #	Description	Est. Quan.	Unit	Bare Costs Mat.	Bare Costs Inst.	Bare Costs Total	Total incl. O&P
1	CONCRETE:						
	Arch	194	C.Y.	18,236	27,160	45,496	59,170
	Beams	7	C.Y.	966	1540	2506	3299
	Slab	3000	S.F.	2820	2160	4980	5940
	Footings	103	C.Y.	7725	3914	11,639	13,905
	Fdn. Walls/Front & Back	11.5	C.Y.	966	1380	2346	3048
	Walls (Front & Back)	40	C.Y.	3360	4800	8160	10,600
	Fdn. Walls (Sides)	63	C.Y.	4850	5985	10,835	13,860
	Vent Shaft	21	C.Y.	2079	3570	5649	7455
						Subtotal	117,268
2	REBARS:						
	Footings	4.13	Tons	2044	1260	3304	4130
	Fdn. Walls	10.75	Tons	5321	2311	7633	9353
	Walls & Arch	50	Tons	24,750	10,750	35,500	43,500
	Floor Slab	3.0	Tons	1476	855	2329	2923
						TOTAL	59,906
3	FORMS:						
	Footings	2940	SFCA	853	3528	4381	5939
	Keyway	360	LF	36	108	144	191
	Beams	825	SFCA	347	1230	1576	2129
	Floor Slab	360	LF	54	350	403	555
	Fdn. Walls	988	SFCA	454	1759	2213	3004
	Front & Rear Walls	2396	SFCA	1102	4265	5367	7284
	Arch & Side Walls	11,520	SFCA	7027	30,847	37,900	51,725
						Subtotal	70,827

guidance

Transportable Unit Storage--Igloo, cont'd

4	FINISHING: Floor: Screed Troweling Walls	3000 3000 5520	SF SF SF	- - 387	480 930 2650	480 930 3036 Subtotal	660 1260 4140 6,060
5	SECURITY DOORS 1-15' x 18' x 14"					Unit Price	124,000
6	MOISTURE PROTECTION: Slab Vapor Barrier (.010 thick) (Arch) Membrane Waterproofing (Front & Rear Walls) Caulking (Reglets)	30 2400 650	Sq S.F. L.F.	162 1992 33	120 1766 42	282 3758 75 Subtotal	350 4670 96 16,792
7	SITE WORK: Excavation (Bldg) Backhoe Footings - Backhoe Excavation (Roadway) Dozer Compacted Backfill Roadway 3" deep stone Erosion Control Fine Grading & Seeding	1443 180 65 2845 89 1550 1550	C.Y. C.Y. C.Y. C.Y. S.Y. S.Y. S.Y.	563 193 70 2874 75 853 279	523 243 17 910 26 233 1395	1086 436 87 3784 101 1085 1674 Subtotal	1374 560 102 4495 716 1271 2217 10,135
						TOTAL	$404,988

Baseline - Transportable Unit Storage - Igloo - Condition B

Item #	Description	Est. Quan.	Unit	Bare Costs Mat.	Bare Costs Inst.	Bare Costs Total	Total incl. O&P
1	CONCRETE:						
	Same as condition A except subtract volume accordingly to reduced portal wall size.					A subtotal	117,268
	Footings	2	C.Y.	150	76	226	- 270
	Fdn. Wall	2	C.Y.	168	240	408	- 530
						Subtotal	116,468
2	REBARS:					A subtotal	59,906
	Footing	.1	Tons	49.5	30.5	80	- 100
	Fdn. Walls & Walls	.34	Tons	169	73	242	- 280
						Subtotal	59,510
3	FORMS:						
	Same as condition A except:						70,827
	Footings	150	SFCA	44	180	224	- 303
	Fdn. Wall	92	SFCA	43	164	207	- 280
						Subtotal	70,244
4	FINISHING						
	Same as condition A						6,060
5	SECURITY DOORS						
	Same as condition A						124,000
6	MOISTURE PROTECTION:						
	Same as condition A except						16,792
	Membrane Waterproofing	50	SF	42	32	74	- 93
						Subtotal	16,700
7	SITE WORK:						
	Excavation (Bldg) (Backhoe)	1660	C.Y.	2108	1959	4067	5146
	Excavation (Roadway) (Dozer)	554	C.Y.	593	144	737	865
	Compacted Backfill	1363	C.Y.	1377	436	1813	2154
	Roadway 3" deep stone	211	S.Y.	180	61	241	275
	Erosion Control	1427	S.Y.	785	214	999	1170
	Fine Grading & Seeding	1427	S.Y.	257	1285	1541	2041
						Subtotal	11,651
						TOTAL	$404,633

Baseline - Transportable Unit Storage - Igloo - Condition C

Item #	Description	Est. Quan.	Unit	Bare Costs Mat.	Bare Costs Inst.	Bare Costs Total	Total incl. O&P
1	CONCRETE:						
	Same as condition A except subtract:					A subtotal	117,268
	Footings (Portal Wall)	14.8	C.Y.	1111	563	1674	- 2000
	Fdn. Wall (Portal Wall)	4.7	C.Y.	398	568	966	- 1255
	Portal Wall	19	C.Y.	1596	2280	3876	- 5035
						Subtotal	108,978
2	REBARS:						
	Same as condition A except:					A subtotal	59,906
	Footing/Fdn.	.77	Tons	381	234	616	- 770
	Portal Wall	.71	Tons	352	153	504	- 618
						Subtotal	58,518
3	FORMS:						
	Same as condition A except:					A subtotal	70,827
	Footing (Portal)	530	SFCA	154	636	790	- 1071
	Fdn. Wall (Portal)	250	SFCA	115	445	560	- 760
	Portal Wall	1024	SFCA	471	1822	2294	- 3313
						Subtotal	65,883
4	FINISHING						
	Same as condition A						6,060
5	SECURITY DOORS:						
	Same as condition A						124,000
6	MOISTURE PROTECTION:						
	Same as condition A except:					A subtotal	16,792
	Membrane Waterproofing	512	S.F.	425	328	753	- 948
						Subtotal	15,844
7	SITE WORK:						
	Excavation (Bldg)	4430	C.Y.	4429	6168	10,854	13,733
	Excavation (Road)	3111	C.Y.	3951	3671	7622	9644
	Compacted Backfill	2565	C.Y.	2591	821	3412	4053
	Roadway - 3" deep stone	444	S.Y.	378	129	507	578
	Erosion Control	1222	S.Y.	672	184	856	1002
	Fine Grading & Seeding	1222	S.Y.	220	1100	1320	1748
						Subtotal	30,758
						TOTAL	410,041

TRANSPORTABLE UNIT SHELTER

RECTANGULAR CONFIGURATION

DCS Transportable Unit Shelter Cost Estimate
Cast-in-Place Concrete Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Cast-in-place concrete	CY	440	200.	88.0
Reinforcing steel	T	94	1000.	94.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		13,400.	13.4
Electrical	LS		75,600.	75.6
Drainage	LS		5,600.	5.6
Waterproofing	SY	1090	5.50	6.0
Excavation	CY	9980	3.00	29.9
Backfill	CY	5710	6.00	34.3
Rock rubble	CY	1700	4.00	6.8
Disposal	CY	4280	2.50	10.7
Seeding	LS		960.	1.0
Unadjusted Facility Costs				$492.8k

Location adjustment factor (Washington, DC)	1.00
Contingency factor	1.05
Supervision and administration factor	1.05
Construction data factor (Jan 84)	1.00

Adjusted Facility Cost $492.8 x 1.00 x 1.05 x 1.05 x 1.00 = $543.3k

*Range between bomb and structure equals 100 ft.

DCS Transportable Unit Shelter Cost Estimate
Precast Segmental Unit Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Precast concrete	CY	470	175.	82.3
Reinforcing steel	T	102	1,000.	102.0
Post-tensioning system	LS		25,000.	25.0
Blast door	LS		127,500.	127.5
Mechanical	LS		13,400.	13.4
Electrical	LS		75,600.	75.6
Drainage	LS		5,600.	5.6
Waterproofing	SY	1120	5.50	6.2
Excavation	CY	10,060	3.00	30.2
Backfill	CY	5,740	6.00	34.4
Rock rubble	CY	1,720	4.00	6.9
Disposal	CY	4,325	2.50	10.8
Seeding	LS		1,000.	1.0
Unadjusted Facility Cost				$520.9k

Location adjustment factor (Washington, DC)	1.00
Contingency factor	1.05
Supervision and administration factor	1.05
Construction data factor (Jan 84)	1.05

Adjusted Facility Cost $520.9k x 1.00 x 1.05 x 1.05 x 1.00 = $574.3k

*Range between bomb and structure equals 100 ft.

DCS Transportable Unit Shelter Cost Estimate
Precast Elements Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Precast concrete	CY	535	175.	93.6
Reinforcing steel	T	118	1,000.	118.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		13,400.	13.4
Electrical	LS		75,600.	75.6
Drainage	LS		5,600.	5.6
Waterproofing	SY	1140	5.50	6.3
Excavation	CY	10,265	3.00	30.8
Backfill	CY	5,815	6.00	34.9
Rock rubble	CY	1,765	4.00	7.1
Disposal	CY	4,455	2.50	11.1
Seeding	LS		1,000.	1.0
Unadjusted Facility Costs				$524.9k
Location adjustment factor (Washington, DC) 1.00				
Contingency factor 1.05				
Supervision and administration factor 1.05				
Construction data factor (Jan 84) 1.00				
Adjusted Facility Cost $524.9k x 1.00 x 1.05 x 1.05 x 1.00 = $578.7				

*Range between bomb and structure equals 100 ft.

DCS Transportable Unit Shelter Cost Estimate
Precast Tilt-up Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Cast-in-place concrete	CY	618	150.	92.7
Reinforcing steel	T	140	1,000.	140.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		13,400.	13.4
Electrical	LS		75,600.	75.6
Drainage	LS		5,700.	5.7
Waterproofing	SY	1,170	5.50	6.4
Excavation	CY	10,550	3.00	31.6
Backfill	CY	5,920	6.00	35.5
Rock rubble	CY	1,820	4.00	7.3
Disposal	CY	4,630	2.50	11.6
Seeding	LS		1,000.	1.0
Unadjusted Facility Cost				$548.3k
Location adjustment factor (Washington, DC) 1.00				
Contingency factor 1.05				
Supervision and administration factor 1.05				
Construction data factor (Jan 84) 1.00				
Adjusted Facility Cost $548.3k x 1.00 x 1.05 x 1.05 x 1.00 = $604.5k				

*Range between bomb and structure equals 100 ft.

DCS Transportable Unit Shelter Cost Estimate
Double Panel Wall Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Cast-in-place concrete	CY	600	200.	120.0
Reinforcing steel	T	135	1,000.	135.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		13,400.	13.4
Electrical	LS		75,600.	75.6
Drainage	LS		5,900.	5.9
Waterproofing	SY	1,350	5.50	7.4
Excavation	CY	11,590	3.00	34.3
Backfill	CY	6,250	6.00	37.5
Rock rubble	CY	2,045	4.00	8.2
Disposal	CY	5,330	2.50	13.3
Seeding	LS		1,100.	1.1
Unadjusted Facility Cost				$579.7k

Location adjustment factor (Washington, DC) 1.00
Contingency factor 1.05
Supervision and administration factor 1.05
Construction data factor (Jan 84) 1.00

Adjusted Facility Cost $579.7k x 1.00 x 1.05 x 1.05 x 1.00 = $639.1k

DCS Transportable Unit Shelter Cost Estimate
Shotcrete Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Shotcrete	CY	500	350.	175.0
Reinforcing Steel	T	110	1,000.	110.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		13,400.	13.4
Electrical	LS		75,600.	75.6
Drainage	LS		5,600.	5.6
Waterproofing	SY	1125	5.50	6.2
Excavation	CY	10,165	3.00	30.5
Backfill	CY	5,775	6.00	34.6
Rock rubble	CY	1,740	4.00	7.0
Disposal	CY	4,390	2.50	11.0
Seeding	LS		1,000.	1.0
Unadjusted Facility Cost				$597.4k

Location adjustment factor (Washington, DC) 1.00
Contingency factor 1.05
Supervision and administration factor 1.05
Construction data factor (Jan 84) 1.00

Adjusted Facility Cost $597.4k x 1.00 x 1.05 x 1.05 x 1.00 = $658.6k

*Range between bomb and structure equals 100 ft.

*Range between bomb and structure equals 100 ft.

TRANSPORTABLE UNIT SHELTER

CIRCULAR CONFIGURATION

DCS Transportable Unit Shelter Cost Estimate
Cast-in Place Concrete Circular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Cast-in-place concrete	CY	415	300.	124.5
Reinforcing steel	T	87	1,200.	104.4
Blast doors	LS		127,500.	127.5
Mechanical	LS		13,400.	13.4
Electrical	LS		75,600.	75.6
Drainage	LS		5,600.	5.6
Waterproofing	SY	870	5.50	4.8
Excavation	CY	10,440	3.00	31.3
Backfill	CY	5,120	6.00	30.7
Rock rubble	CY	1,800	4.00	7.2
Disposal	CY	3,320	2.50	8.3
Seeding	LS		1,000.	1.0
Unadjusted Facility Cost				$539.3k

Location adjustment factor (Washington, DC) 1.00
Contingency factor 1.05
Supervision and administration factor 1.05
Construction data factor (Jan 84) 1.00

Adjusted Facility Cost $521.9 x 1.00 x 1.05 x 1.05 x 1.00 = $594.6k

*Range between bomb and structure equals 100 ft.

DCS Transportable Unit Shelter Cost Estimate
Precast Segmental Unit Circular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Precast concrete	CY	430	250.	107.5
Reinforcing steel	T	90	1,200.	108.0
Post-tensioning system	LS		25,000.	25.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		13,400.	13.4
Electrical	LS		75.6	75.6
Drainage	LS		5,700.	5.7
Waterproofing	SY	875	5.50	4.8
Excavation	CY	10,500	3.00	31.5
Backfill	CY	5,150	6.00	30.9
Rock rubble	CY	1,820	4.00	7.3
Disposal	CY	5,355	2.50	13.4
Seeding	LS		1,000.	1.0
Unadjusted Facility Cost				$551.6k

Location adjustment factor (Washington, DC) 1.00
Contingency factor 1.05
Supervision and administration factor 1.05
Construction data factor (Jan 84) 1.00

Adjusted Facility Cost $551.6k x 1.00 x 1.05 x 1.05 x 1.00 = $608.1k

*Range between bomb and structure equals 100 ft.

DCS Transportable Unit Shelter Cost Estimate
Corrugated Steel/Fibrous Concrete Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Fibrous concrete	CY	96	350.	33.6
Cast-in-place concrete	CY	245	200.	49.0
Reinforcing fibers	LB	25,400	0.50	12.7
Reinforcing steel	T	41	1,000.	41.0
Corrugated steel plate	LS		94,000.	9.4
Foam	SF	8,070	3.00	24.2
Blast doors	LS		127,500.	127.5
Mechanical	LS		13,400.	13.4
Electrical	LS		75,600.	75.6
Drainage	LS		5,600.	5.6
Waterproofing	SY	890	5.50	4.9
Excavation	CY	10,570	3.00	31.7
Backfill	CY	5,175	6.00	31.1
Rock rubble	CY	1,330	4.00	5.3
Disposal	CY	5,400	2.50	13.5
Seeding	LS		1,000	1.0
Unadjusted Facility Costs				$566.1k

Location adjustment factor (Washington, DC)	1.00
Contingency factor	1.05
Supervision and administration factor	1.05
Construction data factor (Jan 84)	1.00

Adjusted Facility Cost $566.1k x 1.00 x 1.05 x 1.05 x 1.00 = $624.1k

*Range between bomb and structure equals 100 ft.

DCS Transportable Unit Shelter Cost Estimate
Shotcrete Circular Construction

Item	Unit Measure	Quant'ty	Unit Cost $	Total Cost $k
Shotcrete	CY	452	400.	180.8
Reinforcing steel	T	96	1,200.	115.2
Blast doors	LS		127,500.	127.5
Mechanical	LS		13,400.	13.4
Electrical	LS		75,600.	75.6
Drainage	LS		5,600.	5.6
Waterproofing	SY	885	5.50	4.9
Excavation	CY	10,585	3.00	31.8
Backfill	CY	5,180	6.00	31.1
Rock rubble	CY	1,835	4.00	7.3
Disposal	CY	5,405	2.50	13.5
Seeding	LS		1,000	1.0
Unadjusted Facility Cost				$607.7k

Location adjustment factor (Washington, DC)	1.00
Contingency factor	1.05
Supervision and administration factor	1.05
Construction data factor (Jan 84)	1.00

Adjusted Facility Cost $607.7k x 1.00 x 1.05 x 1.05 x 1.00 = $669.9k

*Range between bomb and structure equals 100 ft.

RECONSTITUTIONAL PACKAGE SHELTER

RECTANGULAR CONFIGURATION

DCS Reconstitutional Package Shelter Cost Estimate
Cast-in-Place Concrete Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Cast-in-place concrete	CY	290	200.	58.0
Reinforcing steel	T	55	1,000.	55.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		12,200.	12.2
Electrical	LS		54,400.	54.4
Drainage	LS		3,700.	3.7
Waterproofing	SY	495	5.50	2.7
Excavation	CY	6395	3.00	19.2
Backfill	CY	3785	6.00	22.7
Rock rubble	CY	900	4.00	3.6
Disposal	CY	2,610	2.50	6.5
Seeding	LS		500	0.5
Unadjusted Facility Cost				$366.0k
Location adjustment factor (Washington, DC) 1.00				
Contingency factor 1.05				
Supervision and administration factor 1.05				
Construction data factor (Jan 84) 1.00				
Adjusted Facility Cost $366.0k x 1.00 x 1.05 x 1.05 x 1.00 = $403.5k				

*Range between bomb and structure equals 100 ft.

DCS Reconstitutional Package Shelter Cost Estimate
Precast Tilt-up Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Precast concrete	CY	375	150.	56.3
Reinforcing steel	T	75	1,000.	75.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		12,200.	12.2
Electrical	LS		54,400.	54.4
Drainage	LS		3,700.	3.7
Waterproofing	SY	530	5.50	2.9
Excavation	CY	6,765	3.00	20.3
Backfill	CY	3,945	6.00	23.7
Rock rubble	CY	980	4.00	3.9
Disposal	CY	2,825	2.50	7.1
Seeding	LS		600.	0.6
Unadjusted Facility Cost				$387.6k
Location adjustment factor (Washington, DC) 1.00				
Contingency factor 1.05				
Supervision and administration factor 1.05				
Construction data factor (Jan 84) 1.00				
Adjusted Facility Cost $387.6k x 1.00 x 1.05 x 1.05 x 1.00 = $427.3k				

*Range between bomb and structure equals 100 ft.

DCS Reconstitutional Package Shelter Cost Estimate
Precast Tilt-up Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Precast concrete	CY	375	150.	56.3
Reinforcing steel	T	75	1,000.	75.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		12,200.	12.2
Electrical	LS		54,400.	54.4
Drainage	LS		3,700.	3.7
Waterproofing	SY	530	5.50	2.9
Excavation	CY	6,765	3.00	20.3
Backfill	CY	3,945	6.00	23.7
Rock rubble	CY	980	4.00	3.9
Disposal	CY	2,825	2.50	7.1
Seeding	LS		600.	0.6

Unadjusted Facility Cost $387.6k

Location adjustment factor (Washington, DC)	1.00
Contingency factor	1.05
Supervision and administration factor	1.05
Construction data factor (Jan 84)	1.00

Adjusted Facility Cost $387.6k x 1.00 x 1.05 x 1.05 x 1.00 = $427.3k

*Range between bomb and structure equals 100 ft.

DCS Reconstitutional Package Shelter Cost Estimate
Precast Segmental Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Precast concrete	CY	305	175.	53.4
Reinforcing steel	T	58	1,000.	58.0
Post-tensioning system	LS		17,000.	17.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		12,200.	12.2
Electrical	LS		54,400.	54.4
Drainage	LS		3,700.	3.7
Waterproofing	SY	500	5.50	2.8
Excavation	CY	6,450	3.00	19.3
Backfill	CY	3,810	6.00	22.5
Rock rubble	CY	910	4.00	3.6
Disposal	CY	2,640	2.50	6.6
Seeding	LS		510	0.5

Unadjusted Facility Costs $381.9k

Location adjustment factor (Washington, DC)	1.00
Contingency factor	1.05
Supervision and administration factor	1.05
Construction data factor (Jan 84)	1.00

Adjusted Facility Cost $381.9k x 1.00 x 1.05 x 1.05 x 1.00 = $421.0k

*Range between bomb and structure equals 100 ft.

DCS Reconstitutional Package Shelter Cost Estimate
Concrete Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Concrete	CY	320	350.	112.0
Reinforcing steel	T	62	1,000.	62.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		12,200.	12.2
Electrical	LS		54,400.	54.4
Drainage	LS		3,700.	3.7
Waterproofing	SY	[illegible]	5.50	2.8
Excavation	CY	[illegible]	3.00	19.5
Backfill	CY	[illegible]	6.00	23.0
Rock rubble	CY	925	4.00	3.7
Disposal	CY	2,660	2.50	6.7
Seeding	LS		520.	0.5
Unadjusted Facility Cost				$428.0k
Location adjustment factor (Washington, DC)		1.00		
Contingency factor		1.05		
Supervision and administration factor		1.05		
Construction data factor (Jan 84)		1.00		
Adjusted Facility Cost $428.0k x 1.00 x 1.05 x 1.05 x 1.00 = $[illegible]				

*Range between bomb and structure equals 100 ft.

DCS Reconstitutional Package Shelter Cost Estimate
Precast Elements Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Precast concrete	CY	332	175.	58.1
Reinforcing steel	T	65	1,000.	65.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		12,200.	12.2
Electrical	LS		54,400.	54.4
Drainage	LS		3,700.	3.7
Waterproofing	SY	515	5.50	2.8
Excavation	CY	6,580	3.00	19.7
Backfill	CY	3,865	6.00	23.2
Rock rubble	CY	940	4.00	3.8
Disposal	CY	2,720	2.50	6.8
Seeding	LS		500.	0.5
Unadjusted Facility Cost				$377.7k
Location adjustment factor (Washington, DC)		1.00		
Contingency factor		1.05		
Supervision and administration factor		1.05		
Construction data factor (Jan 84)		1.00		
Adjusted Facility Cost $377.7k x 1.00 x 1.05 x 1.05 x 1.00 = $416.4k				

*Range between bomb and structure equals 100 ft.

RECONSTITUTIONAL PACKAGE SHELTER

CIRCULAR CONFIGURATION

DCS Reconstitutional Package Shelter Cost Estimate
Cast in Place Concrete Circular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Cast-in-place concrete	CY	280	300.	84.0
Reinforcing steel	LS	50	1,200.	60.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		12,200.	12.2
Electrical	LS		54,400.	54.4
Drainage	LS		3,700.	3.7
Waterproofing	SY	375	5.50	2.1
Excavation	CY	6,700	3.00	20.1
Backfill	CY	2,950	6.00	17.7
Rock rubble	CY	970	4.00	3.9
Disposal	CY	3,750	2.50	9.4
Seeding	LS		500.	0.5
Unadjusted Facility Cost				$395.5

Location adjustment factor (Washington, DC) 1.00
Contingency factor 1.05
Supervision and administration factor 1.05
Construction data factor (Jan 84) 1.00

Adjusted Facility Cost $395.5k x 1.00 x 1.05 x 1.05 x 1.00 = $436.0k

*Range between bomb and structure equals 100 ft.

DCS Reconstitutional Package Shelter Cost Estimate
Precast Segmental Unit Circular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Precast concrete	CY	290	250.	72.5
Reinforcing steel	T	53	1,200.	63.6
Post-tensioning system	LS		17,000.	17.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		12,200.	12.2
Electrical	LS		54,400.	54.4
Drainage	LS		3,700.	3.7
Waterproofing	SY	380	5.50	2.1
Excavation	CY	6,735	3.00	20.2
Backfill	CY	2,965	6.00	17.8
Rock rubble	CY	975	4.00	3.9
Disposal	CY	3,775	2.50	9.4
Seeding	LS		500	0.5
Unadjusted Facility Cost				$404.8k

Location adjustment factor (Washington, DC) 1.00
Contingency factor 1.05
Supervision and administration factor 1.05
Construction data factor (Jan 84) 1.00

Adjusted Facility Cost $404.8k x 1.00 x 1.05 x 1.05 x 1.00 = $446.3k

*Range between bomb and structure equals 100 ft.

DCS Reconstitutional Package Shelter Cost Estimate
Shotcrete Circular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Shotcrete	CY	300	400.	120.0
Reinforcing steel	T	55	1,200.	66.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		12,200.	12.2
Electrical	LS		54,400.	54.4
Drainage	LS		3,700.	3.7
Waterproofing	SY	385	5.50	2.1
Excavation	CY	6,790	3.00	20.4
Backfill	CY	2,990	6.00	17.9
Rock rubble	CY	985	4.00	3.9
Disposal	CY	3,835	2.50	9.6
Seeding	LS		500	0.5
Unadjusted Facility Cost				$438.2k
Location adjustment factor (Washington, DC) 1.00				
Contingency factor 1.05				
Supervision and administration factor 1.05				
Construction data factor (Jan 84) 1.00				
Adjusted Facility Cost $438.2k x 1.00 x 1.05 x 1.05 x 1.00 = $483.1k				

*Range between bomb and structure equals 100 ft.

OPERATIONAL SHELTER

DCS Integrated Operational and Transportable Unit Shelter Cost Estimate
Cast-in-place Concrete Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Cast-in-place concrete	CY	785	200.	157.0
Reinforcing steel	T	185	1,000.	185.0
Blast doors	LS		127,500.	127.5
Mechanical	LS		50,800.	50.8
Electrical	LS		167,600.	167.6
Drainage	LS		8,000.	8.0
Waterproofing	SY	2,000	5.50	11.0
Excavation	CY	13,510	3.00	40.5
Backfill	CY	6,385	6.00	38.3
Rock rubble	CY	2,690	4.00	10.8
Disposal	CY	7,130	2.50	17.8
Seeding	LS		1,500.	1.5
Unadjusted Facility Cost				$815.8k

Location adjustment factor (Washington, DC) 1.00
Contingency factor 1.05
Supervision and administration factor 1.05
Construction data factor (Jan 84) 1.00

Adjusted Facility Cost $815.8k x 1.00 x 1.05 x 1.05 x 1.00 = $899.4k

*Range between bomb and structure equals 100 ft.

DCS Operational Shelter Cost Estimate
Cast-in-place Concrete Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Cast-in-place concrete	CY	620	200.	124.0
Reinforcing steel	T	145	1,000.	145.0
Blast doors	LS		57,500.	57.5
Mechanical	LS		50,800.	50.8
Electrical	LS		154,200.	154.2
Drainage	LS		4,500.	4.5
Waterproofing	SY	1,490	5.50	8.2
Excavation	CY	10,365	3.00	31.1
Backfill	CY	5,060	6.00	30.4
Rock rubble	CY	1,930	4.00	7.7
Disposal	CY	5,315	2.50	13.3
Seeding	LS		650.	0.7
Unadjusted Facility Cost				$627.4k

Location adjustment factor (Washington, DC) 1.00
Contingency factor 1.05
Supervision and administration factor 1.05
Construction data factor (Jan 84) 1.00

Adjusted Facility Cost $627.4k x 1.00 x 1.05 x 1.05 x 1.00 = $691.7k

*Range between bomb and structure equals 100 ft.

DCS Operational Shelter Cost Estimate
Dome Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Fibrous concrete	CY	140	350.	49.0
Cast-in-place concrete	CY	160	200.	32.0
Reinforcing fibers	LB	25,400	0.50	12.7
Reinforcing steel	T	16	1,000.	16.0
Foam	SF	6,160	6.00	37.0
Blast doors	LS		57,500.	57.5
Mechanical	LS		50,800.	50.8
Electrical	LS		154,200.	154.2
Waterproofing	SY	1,140	5.50	6.3
Drainage	LS		5,600.	5.6
Excavation	CY	160	3.00	0.5
Backfill	CY	9,200	6.00	55.2
Rock rubble	CY	2,360	4.00	9.4
Borrow	CY	8,990	2.50	22.5
Seeding	LS		1,200.	1.2
Unadjusted Facility Cost				$509.9k

Location adjustment factor (Washington, DC) 1.00
Contingency factor 1.05
Supervision and administration factor 1.05
Construction data factor (Jan 84) 1.00

Adjusted Facility Cost $509.8k x 1.00 x 1.05 x 1.05 x 1.00 = $562.2k

*Range between bomb and structure equals 100 ft.

DCS Operational Shelter Cost Estimate
Concrete/Prefabricated Box Form Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Cast-in-place concrete	CY	196	200.	39.2
Reinforcing steel	T	26	1,000.	26.0
Blast doors	LS		57,500.	57.5
Milvans	EA	19	12,500.	237.5
Mechanical	LS		50,800.	50.8
Electrical	LS		154,200.	154.2
Waterproofing	SY	1,010	5.50	5.5
Drainage	LS		5,600.	5.6
Excavation	CY	5,740	3.00	17.2
Backfill	CY	2,170	6.00	13.0
Rock rubble	CY	2,530	4.00	10.1
Disposal	CY	1,040	2.50	2.6
Seeding	LS		1,500.	1.5
Unadjusted Facility Cost				$620.7k

Location adjustment factor (Washington, DC) 1.00
Contingency factor 1.05
Supervision and administration factor 1.05
Construction data factor (Jan 84) 1.00

Adjusted Facility Cost $620.7k x 1.00 x 1.05 x 1.05 x 1.00 = $684.3k

*Range between bomb and structure equals 100 ft.

CASE STUDY

In order to present a realistic application of the results from this investigation, construction cost estimates have been developed for hypothetical operational shelters to be located at Chievres AB, Belgium, near Supreme Headquarters Allied Powers Europe. The shelters were required to withstand overpressures due to blasts from near misses by bombs exploding at ranges of 75 ft or more. Of the several types of semihardened operational shelters, two were considered: the cast-in-place concrete rectangular construction and the fibrous concrete dome construction. The floor plans for the two shelters are presented in Figure G-1 and G-2 respectively. The given floor space areas for the rectangular and dome configurations are 8400 sq ft and 8620 sq ft, respectively. Both structures were covered with 8 ft of soil and rock as shown in Figure D-33. The rectangular shelter was buried while the dome shelter was mounded.

For the purpose of cost estimation, several assumptions were made:

1. The location adjustment factor for Belgium is 1.50
2. The contingency factor is 1.05
3. The supervision and administration factor is 1.05
4. The construction date factor as of January 1984 is 1.00
5. All communications, computer, and UPS equipment will be GFE
6. Other requirements include the following:

a. Total equipment load	- 177 kW (within the shelter)
b. Total manpower	- 30 (within the shelter at one time
c. Special features	- 18 in. raised computer floor required
d. Air conditioning system	- underfloor plenum for supply, space above false ceiling for return; water source heat pump with on-site wells for supply and return
e. Lighting	- Standard ADP and office area lighting levels
f. Fire protection	- Halon underfloor, dry pipe water sprinkler ceiling with manual override
g. Power	- commercial for normal operations, rollout scheme for contingency standby, rotary UPS for backup

The costs associated with item 6 above are reflected principally in the mechanical and electrical estimates for the shelters.

Based on these assumptions, construction cost estimates were developed for the buried rectangular cast-in-place concrete construction and for the mounded fibrous concrete dome construction. The total facility costs were

$1810k and $1786k, and the corresponding unit costs were $215/sq ft and $207/sq ft, respectively. Detailed cost estimates are provided in Tables G-1 and G-2, respectively.

DCS Case Study Cost Estimate:
Cast-in-Place Concrete Rectangular Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Cast-in-place concrete	CY	1,250	200.	250.0
Reinforcing steel	T	312	1,000.	312.0
Blast doors	LS		57,500.	57.5
Mechanical	LS		113,000.	113.0
Electrical	LS		192,400.	192.4
Drainage	LS		7,500.	7.5
Waterproofing	SY	3,120	5.50	17.2
Excavation	CY	18,180	3.00	54.5
Backfill	CY	8,210	6.00	49.3
Rock rubble	CY	3,730	4.00	14.9
Disposal	CY	9,970	2.50	24.9
Seeding	LS		1,400.	1.4
Unadjusted Facility Cost				$1,094.6k
Location adjustment factor (Belgium)		1.50		
Contingency factor		1.05		
Supervision and administration factor		1.05		
Construction data factor (Jan 84)		1.00		
Adjusted Facility Cost $1,094.6K x 1.50 x 1.05 x 1.05 x 1.00 =				$1,810.2k

DCS Case Study Cost Estimate
Multiple Dome Construction

Item	Unit Measure	Quantity	Unit Cost $	Total Cost $k
Fibrous concrete	CY	435	350.	152.2
Cast-in-place concrete	CY	615	200.	123.0
Reinforcing fibers	LB	114,830	0.50	57.4
Reinforcing steel	T	79	1,000.	79.0
Foam	SF	18,500	6.	111.0
Blast doors	LS		57,500.	57.5
Mechanical	LS		110,500.	110.5
Electrical	LS		214,800.	214.8
Waterproofing	SY	3,250	5.50	17.9
Drainage	LS		11,000.	11.0
Excavation	CY	600	3.00	1.8
Backfill	CY	14,540	6.00	87.3
Rock rubble	CY	4,460	4.00	17.8
Borrow	CY	13,950	2.50	34.9
Seeding	LS		4,200.	4.2
Unadjusted Facility Cost				$1,080.3k
Location adjustment factor (Belgium)		1.50		
Contingency factor		1.05		
Supervision and administration factor		1.05		
Construction data factor (Jan 84)		1.00		
Adjusted Facility Cost $1,080.3k x 1.50 x 1.05 x 1.05 x 1.00 =				$1,786.6k

guidance